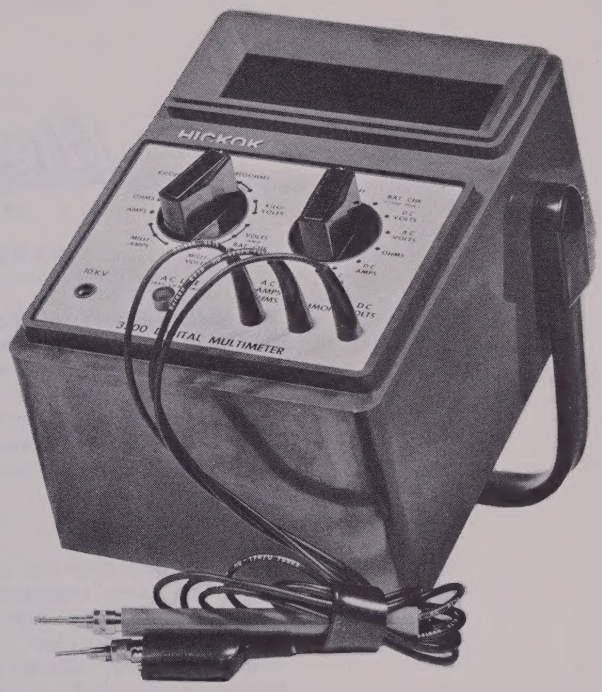
3300

Electronic Calibration Lab
7000 Franklin Blvd., Suite 1220
Sacramento, CA 95823
(916) 392-5404

HICKOK

MODEL 3300
DIGITAL MULTIMETER

HICKOK ELECTRICAL INSTRUMENT COMPANY
10514 Dupont Avenue • Cleveland, Ohio 44108 • Phone 216-541-8060



MODEL 3300

DIGITAL MULTIMETER

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10514 DUPONT AVENUE • CLEVELAND, OHIO 44108

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This warranty does not apply to any of our products which have been repaired or altered by unauthorized persons, or which have been subject to misuse, negligence, or accident, or which have had the serial number altered, effaced or removed. Neither shall the warranty apply where a warranty registration card has not been properly completed and returned to us promptly after purchase. This warranty is in lieu of all other warranties whether expressed or implied.

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19120-158

MODEL 3300 DIGITAL MULTIMETER

TABLE OF CONTENTS

Section		Page
I	GENERAL INFORMATION	1
II	SPECIFICATIONS	1
III	OPERATING INSTRUCTIONS	4
	Battery Operation	4
	AC Operation	4
	Front Panel Markings and Probes	5
	Measurements	5
	DC Volts	5
	AC Volts	5
	Ohms	5
	DC Amps	5
	AC Amps	5
IV	MINIMIZING EXTERNAL SOURCES OF ERROR	6
	Low and High Frequency AC	6
	Harmonic Distortion	6
	Loading Errors, AC	6
	AC Interference on DC Measurements	6
	Dielectric Absorption	6
	Loading Errors, D.C.	6
	Environment	8
	Ohms Measurements	8
V	THEORY OF OPERATION	8
VI	CIRCUIT DESCRIPTION	11
VII	FUNCTIONAL OPERATION	14
	Positive DC Volts	14
	Negative DC Volts	16
	Ohms Operation	16
	Megohms Operation	18
	AC Volts and Current Operation	19
	DC Current Operation	20
VIII	TROUBLESHOOTING	24
	Recommended Equipment	24
	Troubleshooting	24
	1. MOS Integrated Circuit Z2 Outputs and Readouts	24
	2. Integrator Check	25
	3. Comparator Check	25
	4. Input and Self-zero Switching	25
	5. Reference FET Switching and Flip-Flop (Megohms Operation)	26
	6. Output Circuitry and YN	26
	7. AC/DC Converter	26
	8. Function and Range Switching	27
	9. DC Voltage Regulators and Reset Pulse Circuitry	27
	10. Charging Circuit	27
IX	CALIBRATION	27
	Cleaning Procedure	27
	Recommended Calibration Equipment	27
	Calibration Procedure	27
	1. Power Supply	28
	2. Zero Adjust	28
	3. Ohms	28
	4. DC Volts	28
	5. AC Volts	28
	6. Current	28
X	PARTS LIST	29

LIST OF ILLUSTRATIONS

Figure No.		Page
1.	Typical Battery Discharge Curve, Model 3300	4
2.	Basic RC Network	8
3.	Simplified Block Diagram, Time Ratio Integration System	9
4.	Integrator Output	10
5.	Complete Block Diagram	12
6.	Simplified Switching Diagram	17
7.	Ohms Block Diagram	17
8.	Megohms Block Diagram	19
9.	Wave Forms	20
10.	System Wave Forms (Sheet 1 of 3)	21
10.	System Wave Forms (Sheet 2 of 3)	22
10.	System Wave Forms (Sheet 3 of 3)	23
11.	Model 3300, Rear Cover Removed, Parts Location	34
12.	Model 3300, Upper PC Board, Parts Location, Resistors Only	35
13.	Model 3300, Upper PC Board, Parts Location, Capacitor and Transistors	36
14.	Model 3300, Lower PC Board Parts Locations	37
15.	Model 3300, Function and Range Switch Assembly, Top View, Parts Locations	38
16.	Model 3300, Function and Range Switch Assembly, Bottom View, Parts Locations	39
17.	Schematic Wiring Diagram Model 3300 Digital Multimeter	

LIST OF TABLES

Table No.		Page
1.	Range of Average-Dctecting Meter Deviation from True RMS in the Presence of Harmonic Distortion	7
2.	Switching Sequence	10
3.	Sequential Event Chart	15

SECTION I
GENERAL INFORMATION

The Model 3300 Digital Multimeter is a portable instrument with 26 ranges covering ac and dc voltage, ac and dc amperes and resistance. The multimeter may be operated from a 115/230 volt* ac line or from an internal rechargeable battery pack. The batteries permit measurement with complete isolation from power line interference (infinite common mode rejection). Approximately 24-hour battery pack life allows operation in field locations for extended periods of time. The multimeter may also be operated from the ac power line while the battery pack is being recharged.

* See schematic diagram for 230 volt connections.

The bright fluorescent digital display consists of seven-segment numerical indicators which provide a maximum display of 1999. Display features include an automatic polarity indicator, automatically positioned decimal point, and overrange indication. The reading rate is once per second. Overrange is indicated by a blanked display which occurs when the readings exceed 1999.

The test probes are permanently attached to the front panel and are fitted with a captive strap which conveniently secures the probes on the combination carrying handle and tilt stand. The test lead for AC VOLTS, AMPS and OHMS is straight through with a prod tip. The COMMON lead is also straight through but is provided with an alligator clip. The DC VOLTS lead is fitted with a one-megohm resistor in the prod to minimize circuit loading.

Operator convenience and safety have been stressed in the design of the Model 3300. For operator protection on high voltage measurements the case is completely isolated from the input terminals and contains no metal parts, and all probes not in use are open circuited. A color-coded front panel is provided for ease in the selection of the 26 ranges. A high input impedance minimizes erroneous reading from loading of the circuit under test. The Model 3300 incorporates circuitry which prevents damage to the unit in case of overloads or improper switch settings. Only the probes selected by the switch settings are connected to internal circuitry and no damage to the instrument will result if the wrong probes are used or if the instrument has been incorrectly set up. A high impact resistant plastic case, shock mounted readout and wide temperature operating range make this a rugged instrument for field applications as well as for laboratory and production line use.

SECTION II
SPECIFICATIONS

FUNCTIONS

AC and DC Volts

AC and DC Current

Resistance

RANGES

AC and DC Volts

Range	Reading	Resolution
100 mV	000.0 to 199.9 mV	100 microvolts
1 V	0.000 to 1.999 V	1 millivolt
10 V	00.00 to 19.99 V	10 millivolts
100 V	000.0 to 199.9 V	100 millivolts
1 kV[1]	0.000 to 1.500 kV	1 volt
10 kV probe[2]	0 to 15.00 kV	10 volts

[1] 1000V rms max. ac input

[2] dc only

RANGES (Continued)

AC and DC Current

Range	Reading	Resolution
1 mA	0.000 to 1.999 mA	1 microampere
10 mA	00.00 to 19.99 mA	10 microamperes
100 mA	100.0 to 199.9 mA	100 microamperes
1 A	0.000 to 1.999 A	1 milliampere

Ohms

Range	Reading	Resolution	Polarity Common	Polarity Probe	Current	Power in Rx @ full scale
100Ω	000.0 to 110.0Ω	0.1Ω	-	+	250 u A	6.25 u W
1kΩ	0.000 to 1.00kΩ	1.0Ω	-	+	25 u A	0.625 u W
10kΩ	00.00 to 11.00kΩ	10Ω	-	+	2.5 u A	0.0625 u W
100kΩ	000.0 to 110.0kΩ	100Ω	-	+	0.25 u A	0.00625 u W
1MΩ	0.000 to 1.999MΩ	1kΩ	+	-	250 u A	6.25 u W
10MΩ	00.00 to 19.99MΩ	10kΩ	+	-	25 u A	0.625 u A
100MΩ	000.0 to 199.9MΩ	100kΩ	+	-	2.5 u A	0.0625 u W

Maximum open circuit voltage: 2.5V

OVERLOAD PROTECTION

AC Volts	Ohms
250 V on 100 mV ranges	100 V on 100Ω range
1000 V on all other ranges	250 V on all other ranges
DC Volts	**Current**
1000 V on 100 mV range	10 times full scale on all ranges
1500 V on all other ranges	

OPERATING TEMPERATURE RANGE

0° to 50° C

ACCURACY

Function	Range	Accuracy at 20° C to 30° C	Temperature Coefficient 0-19° C 31-50° C
DC VOLTS	10 mV to 1500 V	0.1% of reading ±1 digit	150 ppm/C°
	10 kV probe	5.0% of full scale	150 ppm/C°
AC VOLTS	100 mV to 1000 V		
	22 Hz to 50 Hz	1.5% of full scale ±2 digits	200 ppm/C°
	50 Hz to 50 kHz	0.5% of full scale ±2 digits	200 ppm/C°
	50 kHz to 100 kHz	1.0% of full scale ± 2 digits	200 ppm/C°
NOTE: Max. frequency on 1kV ac range is 10 kHz.			
DC AMPS	All	0.2% of reading ±1 digit	200 ppm/C°

ACCURACY (Continued)

Function	Range	Accuracy at 20° C to 30° C	Temperature Coefficient 0-19° C 31-50° C
AC AMPS	All		
	22Hz to 50 Hz	1.5% of full scale ±1 digit	200 ppm/C°
	50 Hz to 50 kHz	0.5% of full scale ±1 digit	200 ppm/C°
	50 kHz to 100 kHz	1.0% of full scale ±1 digit	200 ppm/C°
OHMS	All	0.3% of full scale ±1 digit	200 ppm/C°

NOTE: Add 0.1% of reading to accuracy specs. when operated during battery charge

INPUT ISOLATION FROM GROUND

Infinite when operated on batteries.

1500 volts peak when line operated (batteries charging).

INPUT IMPEDANCE AT PROBE TIP

dc: 11 megohms/5pF; includes 1 megohm isolation resistor.

ac: Approx. 200 pF.

COMMON MODE REJECTION (with 1K ohm source imbalance)

Battery operation:	Infinite
Line operation (on recharge):	120 dB at 60 Hz, 90 dB at 1 kHz

NORMAL MODE REJECTION

50 dB at 40 Hz

60 dB at 60 Hz

70 dB at 120 Hz

DISPLAY

7-segment numerical indicators

Maximum display of 1999

Automatically positioned decimal point

Automatic polarity indicator

Out-of-range indication

Display rate: once per second

PROBES

Permanently Attached

AC VOLTS, AMPS, OHMS	Straight through with prod tip
COMMON	Insulated alligator clip
DC VOLTS	1 megohm isolation resistor in prod

OPERATING POWER REQUIREMENT

Internal rechargeable battery, or 115/230* volts ac ± 20%

50/400 Hz 5 watt line operation (battery charging)

DIMENSIONS

8" high x 5-7/8" wide x 4" deep

WEIGHT

6 pounds

* See schematic diagram for 230 volt connections.

SECTION III
OPERATING INSTRUCTIONS

The Model 3300 Digital Multimeter is designed to operate from either its internal battery pack or a 115V/230V*, 50-400 Hz ac power source. The rechangeable nickel-cadmium batteries are permanently installed inside the unit and recharge directly from the ac power line. The multimeter will operate up to 24 hours, starting with charged batteries, whether operated continuously or intermittently. Recharge time for the battery pack is 16 hours or less, depending on the state of the batteries.

* See schematic diagram for 230 volt connections.

An ac line cord is permanently attached to the multimeter. It is stored in a receptacle in the rear panel when not in use.

BATTERY OPERATION

The multimeter will operate on its batteries whenever the line cord is not plugged into an ac outlet. To recharge the batteries, plug the line cord into a power outlet. The AC LINE (BAT. CHARGING) light on the front panel will glow, indicating that the batteries are charging.

A battery check, Figure 1, is incorporated in the unit to test the battery level. To check the batteries, set the function switch, on the right, to BAT. CHK and the range switch, on the left, to any VOLTS position; the readout will then display a number. If the number is greater than 1300 the multimeter is ready for operation. However, if the number is less than 1300 the batteries must be recharged. A full recharge will take approximately 16 hours.

AC OPERATION

The switch to ac operation takes place automatically when the line cord is plugged into an ac power source. This also charges the batteries, even with the multimeter turned off.

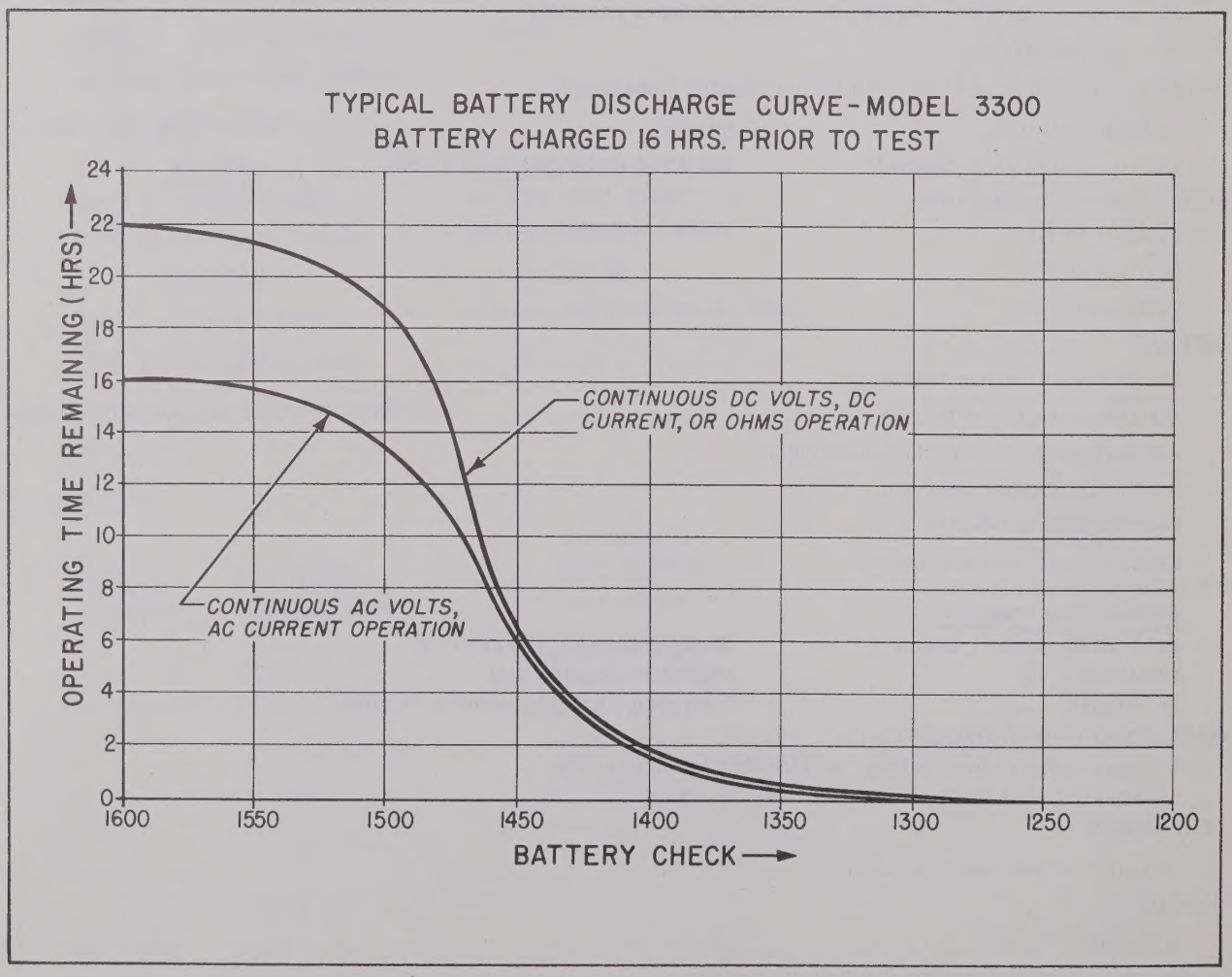


Figure 1. Typical Battery Discharge Curve, Model 3300

CAUTION

Whenever the Model 3300 Digital Multimeter is operated on ac power, the common lead must not be elevated in excess of 1500 volts ac peak plus dc as referenced to ac power source ground. This limitation is necessary because of the breakdown rating of the transformer.

FRONT PANEL MARKINGS AND PROBES

The front panel is color-coded for ease of operation. Each setting and probe has a characteristic color. The battery check is blue, the voltage settings are red, resistances are green and the current settings are yellow.

The probes are color-coded to eliminate the need to trace the leads to the front panel to distinguish between them. The black alligator clip is the COMMON lead, the red probe is for DC VOLTS and the black probe is for all other measurements. High dc voltage measurements, over 1500V, must be made through the 10kV jack, and must be made with a special high voltage probe (Hickok part number 16970-101). No measurements over 1000 V ac rms may be taken; the 10kV probe is for dc voltages only, not exceeding 15kV.

MEASUREMENTS

Five types of measurements can be made with the Model 3300. They are: AC VOLTS, DC VOLTS, AC AMPS, DC AMPS and OHMS. Each type of measurement is selected by setting the function switch, the right-hand switch, to the proper position and the range switch, the left-hand switch, to the desired range. Then the correct probes are selected to make the measurements.

The function switch selects the type of measurement to be made. The range switch sets the full scale value for that measurement. Each position on the range switch is labeled in the units to be measured and the decimal point is automatically positioned for that unit of measure. As an example, there are three positions labeled "VOLTS". The unit is volts, the three positions are X.XXX volts, XX.XX volts and XXX.X volts. Therefore, on the XXX.X volts range, the largest voltage that can be read is 199.9 volts. In all functions, if an unknown quantity is to be measured the range switch should be set to the highest range and then switched to lower ranges as required for a three or four digit reading.

DC Volts

DC voltage measurements are made by setting the function switch to DC VOLTS and the range switch to the proper voltage range. Using the black alligator clip and the red probe, the Model 3300 may then be used similarly to any voltmeter. The Model 3300 incorporates circuitry which enables it to withstand overloads up to 1000 volts on the 100 mV range and 1500 volts on all other ranges.

CAUTION

When measuring high voltage through the 10kV jack, the 10kV Probe (Hickok part number 16970-101) must be used. These measurements should not exceed 15kV.

AC Volts

AC voltages are measured by setting the function switch to AC VOLTS and the range switch to the correct voltage range. Allow several seconds for the ac/dc converter to stabilize before taking the measurement. With the black probe and the alligator clip being used, the multimeter will operate similarly to any other voltmeter. AC functions are overload protected for inputs of up to 250 volts rms on the 100 mV range and 1000 volts rms on all other ranges.

Ohms

Resistance is measured by setting the function switch to OHMS and the range switch to the desired resistance range. The alligator clip and black probe are used to make the measurement. In all ohms ranges the probe is positive and in all megohms ranges the probe is negative. Maximum open circuit voltage is 2.5 volts on all ranges. When the multimeter is set up for ohmmeter use, the display will blank when not measuring a resistance or when the resistance is greater than 1999 on the range selected. Open leads would be infinite resistance and therefore an overrange condition. The ohmmeter section is protected for input voltages up to 100 volts on the 100 ohm range and 250 volts on all other ranges.

DC Amps

DC amperes are measured by setting the function switch to DC AMPS and the range switch to the desired current range. To make the measurement use the black probe and the alligator clip.

AC amps

AC amperes are measured by setting the function switch to AC AMPS and the range switch to the proper current range. Allow several seconds for the ac/dc converter to stabilize before making the measurement. To make the measurement use the black probe and the alligator clip. The current shunts and associated circuitry have been designed to withstand overloads of up to ten times full scale on all ranges. Overloads above ten times full scale may permanently damage the precision current shunts but will not affect other circuits.

CAUTION

Elevated voltage and current measurements may be made in both battery and ac line operation. In ac line operation the total voltage must not exceed 1500 volts ac peak plus dc. In battery operation the total voltage must not exceed 5kV ac peak plus dc; however, the maximum input levels of 1000 volts rms on ac and 1500 volts on dc must always be observed. Extreme caution is always necessary when high voltages are present.

SECTION IV
MINIMIZING EXTERNAL SOURCES OF ERROR

The multimeter is an exceptionally accurate and stable instrument. Operator convenience and measurement simplicity have been stressed throughout. Unique circuit design, special compensation techniques, and stable components have eliminated the necessity for front panel zero or calibration controls. If inaccuracies are encountered, the measurement setup external to the unit should be carefully checked.

The multimeter will measure dc volts and current, ac volts and current, and ohms to a high degree of accuracy. Attention to the details outlined in the following paragraphs will minimize external sources of error and help the operator to achieve maximum accuracy.

LOW AND HIGH FREQUENCY AC

When taking ac measurements it is important to remember that the multimeter is designed to roll off with ac inputs below the 22 Hz lower frequency specification. Since 100% rejection of these signals is not possible, the presence of such inputs will cause fluctuations in the display reading.

The ac/dc converter is limited in frequency response to 500kHz. Because of this limitation the accuracy of measurements for signals over 100kHz is not specified and measurements in this range are not recommended.

HARMONIC DISTORTION

Average reading instruments such as this multimeter are calibrated in rms for pure sinusoidal inputs. However, in the presence of harmonic distortion, average reading instruments will deviate from the true rms value as a function of the relative amplitude, phase, and order of the harmonic with respect to the fundamental. Table 1 provides error limit values for distortion levels of 0.1% for the second and third order harmonics.

LOADING ERRORS - AC

The ac input impedance of the multimeter is designed to be as high as is practically possible. However, when voltage measurements are required to the full accuracy of the instrument the internal impedance of the voltage source should be considered.

AC INTERFERENCE ON DC MEASUREMENTS

It is often necessary, or convenient, to measure dc voltages in the presence of large ac voltages. This is most often the case when measurements are taken on equipment which is in normal operation; for example, measuring the collector voltage of a large signal pulse amplifier stage, or grid bias shifts in class B amplifiers. Further, unshielded high impedance circuits are subject to pickup of large voltages from nearby electrostatic fields, such as the 60 Hz line, fluorescent lights, etc. For these reasons the multimeter is designed to accept large ac voltages across its input terminals and still give an accurate indication of the dc component.

This ability to discriminate between ac and dc signals is an outstanding feature of this instrument. It is accomplished by two means: first, the input voltage is filtered by a conventional R-C network; then, the integrator amplifier, with a ramp peak of 10 volts and an integration time of 100 milliseconds, eliminates the remaining fluctuations.

The multimeter is specified to have, for example, a 60 dB rejection of 60 Hz interference. This means that the apparent reading error (which may be either plus or minus) will be 1/1000 (one thousandth) of the impressed ac value. To illustrate, if we add one volt rms of 60 Hz ac to one-half volt dc, we will have an extra error of 0.001 volt. Consequently, our readings could shift by ± 2 digits. So, as a result of adding one volt 60 Hz ac, we have added 0.001 volt of uncertainty to our final reading - a very small error. However, it is preferable to keep the ac voltages within the limits allowed for ± 1 digit of error.

DIELECTRIC ABSORPTION

Dielectric absorption is associated with insulating materials and is inherent in their chemical structure. This multimeter has been carefully designed to reduce this effect within itself, but it may occur in the external circuitry. After a capacitor has been charged and then shorted out, a small percentage of the original voltage will reappear across it after a time, thus requiring a second discharge. The capacitor may persist for several hours in generating these small voltages. Thus, care should be taken when a high voltage measurement is followed by a very low voltage measurement in a circuit with questionable dielectric absorption.

LOADING ERRORS - DC

Whenever voltage measurements are required to the full accuracy of the multimeter, the internal impedance of the voltage source should be considered. The input impedance of the multimeter was designed to be as high as possible, but if the internal impedance of the voltage source exceeds 5k ohms it must be taken into account. The input impedance of the multimeter is 11 megohms ± 0.1%. Consequently, an 11k ohms source impedance will cause the unit to read 0.1% low; a 110k source impedance

Harmonic Number	Form of Distortion Relative to $\sqrt{2}\sin\omega t$ Fundamental	Composite Waveform		Error Limit	Average meter indication limit of error vs. true rms (in %)					
		Average Meter	RMS Value		Distortion Level					
					0.1%	0.3%	1%	2%	5%	10%
2	$\pm a\sqrt{2}\cos 2\omega t$	$1+\frac{a^2}{2}-\frac{5}{8}a^4$	$1+\frac{a^2}{2}-\frac{a^4}{8}$	Minimum Negative	0.00	0.00	0.00	0.00	0.00	-0.01
	$\pm a\sqrt{2}\sin 2\omega t$	1	$\sqrt{1+a^2}$	Maximum Negative	0.00	0.00	-0.01	-0.02	-0.12	-0.50
3	$a\sqrt{2}\sin 3\omega t$	$1+\frac{a}{3}$	$\sqrt{1+a^2}$	Maximum Positive	+0.03	+0.10	+0.33	+0.65	+1.54	+2.82
	$-a\sqrt{2}\sin 3\omega t$	$1-\frac{a}{3}$	$\sqrt{1\quad a^2}$	Maximum Negative	-0.03	-0.10	-0.34	-0.68	-1.79	-3.81

Notes: a = fractional distortion level = $\frac{\%\text{ distortion}}{100}$

Percentage error (average meter vs. true rms) = $\frac{E_{\text{indicated average meter}} - E_{\text{rms}}}{E_{\text{rms}}} \times 100\%$

Percentage error (average meter vs. fundamental = $(E_{\text{indicated average meter}} - 1) \times 100\%$

Percentage error (rms meter vs. fundamental) = $\frac{E_{\text{rms}} - E_{\text{fundamental}}}{E_{\text{fundamental}}} \times 100\% \approx +\frac{a^2}{\quad} \times 100\%$

The following three rules apply:

Rule 1: An n^{th} order odd harmonic may, depending upon phase, increase or decrease the average value by as much as 1/n times its relative amplitude, for distortion up to (100/n)%. An average-detecting meter indication is in error by this shift corrected by the amount of the distortion's effect on the true rms value.

Rule 2: An even harmonic that is in phase with the fundamental, for distortion up to (100/n)%, does not affect the average value.

Rule 3: An even harmonic in quadrature with the fundamental increases the average value in approximately the same manner as it increases the rms value.

Table 1. Range of Average-Detecting Meter Deviation from True EMS in the Presence of Harmonic Distortion

will cause a 1% drop in reading. Corrections for loading can be made when the source impedance is known by applying the following formula:

$$\text{True voltage} = \text{multimeter reading} + \text{multimeter reading} \times \left(\frac{\text{source impedance in ohms}}{11 \times 10^6}\right)$$

By using the formula, loading errors can be kept below 0.1% for source impedances as high as 10^7 ohms.

ENVIRONMENT

A number of possible sources of error are introduced by severe environments. The multimeter is designed to eliminate as many of these as possible. Both temperature and humidity factors have been taken into account. The unit's specified accuracy will be retained over a temperature range of 20°C to 30°C. Humidity effects have been reduced by extremely careful treatment of insulating surfaces. If errors are encountered which can only be attributed to environmental changes, these will most likely be found in the external measurement setup.

Corrosive atmospheres, particularly when the humidity is high, can cause large leakage currents. The multimeter is totally enclosed and should not be opened or otherwise exposed to industrial atmospheres. The test setup as well should be kept as clean as possible. In the event of difficulties, clean, dry Freon TF mixed with Dow-Corning Silicone Oil DC 200 in a ratio of 50:1 should be used to carefully clean contaminated binding posts, switches or other leakage paths.

OHMS MEASUREMENTS

AC rejection on the ohms ranges is the same as is specified for the other ranges: a 60 Hz signal in excess of 60 dB will cause a fluctuation in the reading (input sensitivity is 25mV/1000 counts). The maximum sensitivity of the ohmmeter circuit is 0.1 ohms per digit on the 100 ohm range. As in any low range ohmmeter, contact resistance can become a significant portion of the total resistance being measured and must be considered. Careful attention to circuit connections can minimize these errors. High impedance measurements, in the megohms region, are subject to pickup of large voltages from nearby electrostatic fields. Careful attention to lead length, component placement and shielding will minimize pickup on high resistance measurements. External leakage paths through insulation material associated with the resistance under measurement can also cause error. In effect, these leakage paths form resistance paths in parallel with the true resistance, thus reducing the value. All of these are external effects and should be taken into account whenever there is doubt in the reading.

SECTION V
THEORY OF OPERATION

The multimeter utilizes a triple segment sequence time ratio integration technique that converts a dc input voltage to a number of pulses. The number of pulses is directly related to the dc input voltage and is internally counted and displayed. The cycle time is approximately one second. At the beginning of each cycle an internally generated reset pulse resets the counters to zero and the system again samples the input dc voltage. The actual input sample time is approximately 100 milliseconds and the remaining 900 milliseconds is used for comparison, self-zeroing and display.

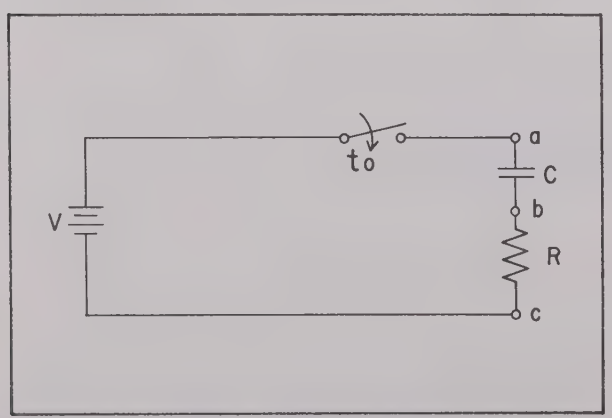


Figure 2. Basic RC Network

All functions on the multimeter use this dc to count conversion. In ac volts, alternating current, direct current, and ohms, the quantity being measured is converted to a dc voltage. This dc voltage is then measured and displayed.

The analog-to-digital conversion is accomplished through the use of a basic principal of electricity.

In figure 2, the expression for the voltage across the capacitor for time after the switch is closed is:

$$Vab = \frac{1}{C} \int_o^t idt \qquad (1)$$

It is obvious from the circuit that the capacitor will charge to the battery voltage at a rate determined by R and C. Equation (1) is the integral form for the charge voltage as a function of time (assuming no charge on the capacitor prior to switch closure). The current, i, in equation (1) is a time varying current and the solution of the equation yields the well-known exponential charge curve for the voltage across C.

However, if i is made constant by use of a constant current generator, large R, or other means, then the solution of equation (1) is a linear ramp voltage dependent only on time.

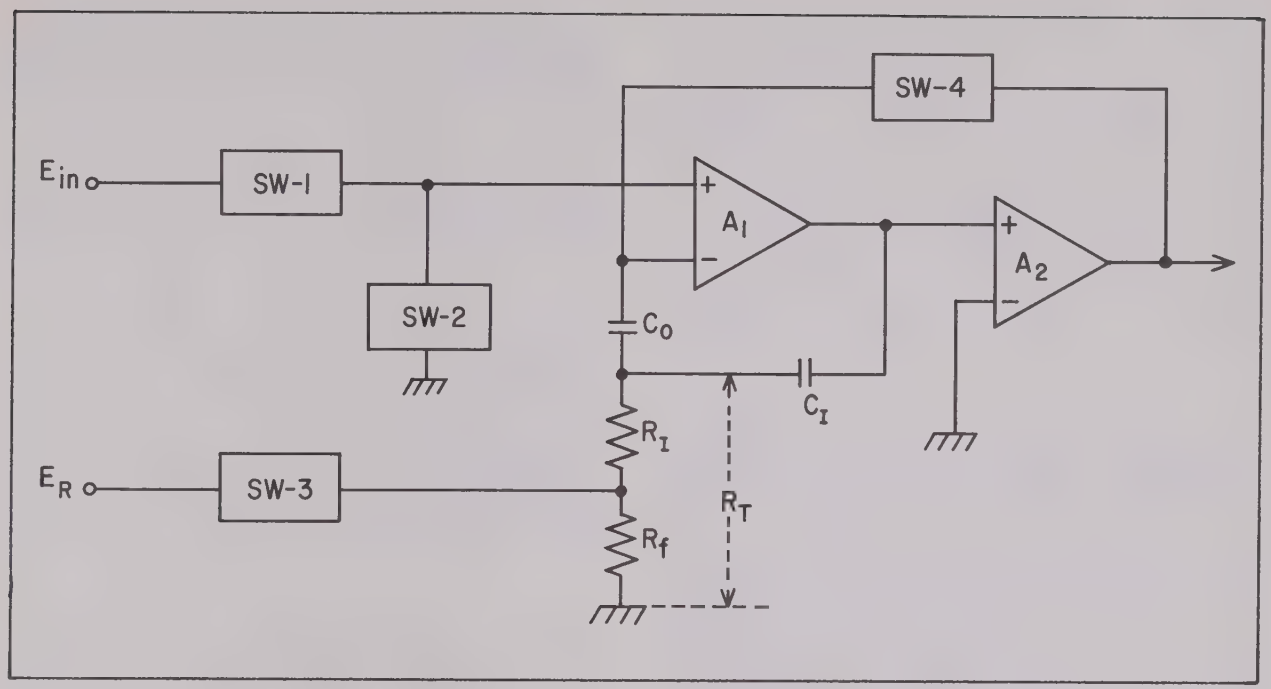


Figure 3. Simplified Block Diagram, Time Ratio Integration System

$$Vab = \frac{1}{C} \int_0^t idt$$

$$Vab = \frac{1}{C} \int_0^t Idt$$

$$Vab = \frac{I}{C} (t) \qquad (2)$$

Equation (2) illustrates the fact that the voltage across C, when I is constant, is a ramp voltage whose slope is dependent on I and whose magnitude varies with time. Therefore, since time is the only variable, the ramp voltage is linear, i.e., not exponential, if C is a perfect capacitor.

It is also important to note that the voltage across the resistor in figure 2 is equal to the source voltage minus the voltage across the capacitor.

At the time the switch is closed, $t = 0^+$, $I = 0$ and equation (1) yields zero voltage across the capacitor, as one would expect since the voltage across the capacitor cannot change instantaneously. Therefore, the full source voltage appears across terminals b and c or across R. Of significance is the fact that if R is infinite then $I = o$ for all time then equation (1) is zero for all time, i.e., if R is infinitely large, then the capacitor drops no voltage and the voltage applied appears at the output or across terminals b and c.

These two theories comprise the basis for a unique, automatic zeroing, analog-to-digital converter used in this multimeter.

The simplified block diagram shown in figure 3 is the basic time ratio integration system. Amplifier A_1 is a high gain, high input impedance differential amplifier. Components C_I, R_I and R_f are the integration network. Capacitor C_O is the self-zeroing storage capacitor. Amplifier A_2 is a zero crossing detector.

The output of amplifier A_1 is always equal to the difference between the inverting input and non-inverting input times the gain as shown in equation (3).

$$E \text{ out } A_1 = (E_{in} - E_f) A \qquad (3)$$

Therefore, the output of A_1 is a large voltage if E_{in} and E_f are not equal. A_1 has a gain of approximately 10,000 so that a very small difference at the two inputs will drive the amplifier into saturation. This means that in order to balance the amplifier E_f must equal E_{in} for all practical purposes.

The conversion sequence begins with a condition in which SW-1 is open, removing E_{in} from the amplifier; SW-2 is closed, grounding the non-inverting input of the amplifier; SW-3 is open, removing the reference voltage; SW-4 is closed, setting the system into self-zero mode.

The output of amplifier A_2 is positive when its input is positive, negative when its input is negative and zero when its input is zero (neglecting offset). With SW-4 closed, the output of A_2 is connected

to the inverting input of A_1 and capacitor C_o. This comprises a closed loop from the output to the input of the over-all system. Feedback from A_2 to A_1 stabilizes the over-all system in a condition where necessary offset voltage is self-generated and stored in capacitor C_o. In self-zero mode, if offsets in the amplifiers tend to drive the output of A_2 positive or negative, a voltage will be developed at the inverting input of A1 of such magnitude as to compensate for the amplifiers offset. This voltage is stored in C_o and remains constant during the conversion sequence due to the high input impedance of A_1. After each conversion sequence SW-4 is again closed, up-dating the offset voltage for each cycle.

The system is now stabilized in a self-zero condition. The input sampling is accomplished by opening SW-2, SW-4 and closing SW-1, applying E_{in} to the non-inverting input of A_1. A_1 sees a step input from zero volts to E_{in}. At this time the inverting input is zero, so amplifier A_1 will tend to saturate positive. However, the step input to A_1 produces a step output and since the charge on C_I cannot change instantaneously this step appears at the top of R_I and at the inverting input through C_o. Therefore, instead of saturating, A_1 output steps from zero volts to a magnitude equal to E_{in} which balances the two inputs. (Note that C_o acts as a short circuit to voltages at R_I since A_1 input impedance is very high.) This condition would exist only momentarily since the inverting input is always equal to the voltage across R_I and R_f.

$$E_f = I(R_I + R_f)$$

$$R_I + R_f = R_T$$

$$E_f = IR_T \qquad (4)$$

In order to keep the input to A_1 balanced, a constant current as required in equation (4) must flow through R_T. This constant current is supplied by A_1 charging C_I at a constant rate. As discussed, a constant current through C_I necessitates a linear ramp voltage across C_I: therefore, the output of A_1 steps from zero to E_{in} and then ramps positive (if E_{in} is positive) linearly.

This closed loop feedback system is stable as long as $E_{in} = E_f$ or when the current through C_I is constant as required by equation (4).

The output of A_1 is the voltage across R_I, R_f and C_I.

$$V_{out} = \frac{I}{C_I}(t) + E_f$$

Since $E_{in} = E_f$ and from equation (4) $I = \frac{E_f}{R_T}$

$$V_{out} = \frac{\frac{E_{in}}{R_T}}{C_I}(t) + E_{in}$$

or

$$V_{out} = \frac{E_{in}}{R_T C_I}(t) + E_{in} \qquad (5)$$

Equation (5) is the expression for the voltage at the output of A_1 as a function of time, where the input voltage is E_{in}. This voltage steps, then increases linearly if E_{in} remains constant.

A similar condition exists if the non-inverting input of A_1 is set to zero (SW-1 open, SW-2 closed) and a positive voltage is applied through SW-3. This condition places a voltage E_R at the bottom of R_I. The non-inverting input of A_1 has stepped from E_{in} to zero so the output steps negative by E_{in} volts to again balance the two inputs. However, in order to maintain this balance condition there must exist a current through R_T to offset the reference voltage E_R. The magnitude of this current was expressed in equation (4).

Therefore, when E_{in} is removed and the reference is applied, the output of A_1 steps negative then ramps negative to produce a net sum of zero volts across R_T and therefore balanced inputs again at A_1.

The expression for the output of A_1 during this negative portion of the ramp is:

$$V_{out} = -\frac{E_R}{R_T C_I}(t) - E_{in} \qquad (6)$$

If the switches shown in figure 3 are sequenced in specific order, the output of A_1 may be made to ramp positive for a period of time while E_{in} is applied and negative for a period of time while E_R is applied. A ramp similar to that shown in figure 4 would be produced for the sequence shown in table 2.

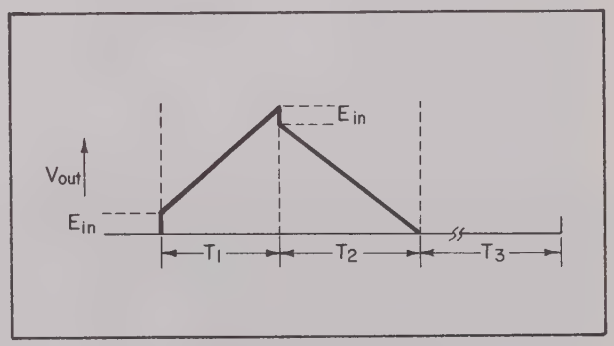


Figure 4. Integrator Output

Time	SW-1	SW-2	SW-3	SW-4
T_1	ON	OFF	OFF	OFF
T_2	OFF	ON	ON	OFF
T_3	OFF	ON	OFF	ON

Table 2. Switching Sequence

The equations for the up ramp and down ramp are (5) and (6). These equations are for all time but, in order to compare the unknown input voltage to a known reference voltage, the time it takes to charge C_I is compared to the time it takes to discharge C_I.

In figure 4 and table 2, if time T_1 is set to a specific value and time T_2 measured, then E_{in} is to T_1 as E_R is to T_2, or:

$$\frac{E_{in}}{E_R} = K \frac{T_1}{T_2} \qquad (7)$$

In this multimeter an oscillator is gated ON when E_{in} is applied to A_1 and allowed to run for 1000 cycles. At this point E_{in} is removed and E_R is applied and the oscillator continues to run during time T_2, for N_X cycles, until the output of A_1 again reaches zero volts (starting point). Therefore, from equation (7) E_{in} is related to E_R by the ratio of two series of pulses.

Since the increase in voltage out of A_1 during T_1 is equal to the decrease in voltage out during T_2 (returned to same voltage level) equations (5) and (6) must be equal at time T_1 and at time T_2.

$$T_1 = \frac{1000}{f} \qquad (8)$$

$$T_2 = \frac{N_X}{f} \qquad (9)$$

f = oscillator frequency

N_X = number cycles during time T_2

Substituting equation (8) and (9) into equations (5) and (6) and equating the two:

$$\frac{E_{in}}{R_T C_I}\left(\frac{1000}{f}\right) + E_{in} = \frac{E_R}{R_T C_I}\left(\frac{N_X}{f}\right) + E_{in}$$

Simplifying:

$$\frac{E_{in}}{R_T C_I f} \quad 1000 = \frac{E_R}{R_T C_I f} \quad \left(N_X\right)$$

and:

$$N_X = \frac{E_{in}}{E_R} \left(1000\right) \qquad (10)$$

Therefore, the number of pulses during the application of the reference voltage is proportional to the input voltage and the reference voltage.

If N_X is displayed on some type of readout device and the constant, $\frac{1000}{E_R}$, is adjusted to make N_X directly proportional to E_{in}, the system would then be a single-range voltmeter.

The accuracy of the analog-to-digital conversion is dependent only on the reference voltage. The frequency of the oscillator, amplifier gain, integrating capacitor and resistor do not appear in equation (10) and do not affect the accuracy of the system as long as they are within reason.

Most significant is the fact that the over-all system is automatically zeroed prior to each cycle and is able to maintain exceptional stability during the cycle. Zero drift and the subsequent offset in readings have been eliminated.

SECTION VI
CIRCUIT DESCRIPTION

The circuitry discussed in Theory of Operation plus the circuitry necessary to count and display N_X and thereby indicate the magnitude of the units being measured is shown schematically in figure 16 and block diagram form in figure 5.

The basic system has a full scale input sensitivity of 90.909 mV and is linear up to 100% overrange. All ranges are divided down to this level as a particular full scale input range is selected.

Range Switch S2

The range switch sets the full scale input value on all functions. This switch selects the appropriate dividers or range resistors to produce 90.909 mV input to the integrator for a full scale reading.

Function Switch S1

The function switch selects the particular unit to be measured. These units are dc volts and current, ac volts and current, and ohms. The function switch has provisions for checking battery voltage and de-energizing the unit. The appropriate test probe is also connected to the unit via the function switch.

Filter

The integrator input filter consists of an RC network which, when combined with the integrator, provides high ac noise rejection. The rejection is specified in Section II.

SW-1 and SW-2

SW-1 and SW-2 are the input switches consisting of junction FET's Q2 and Q4 and are controlled by

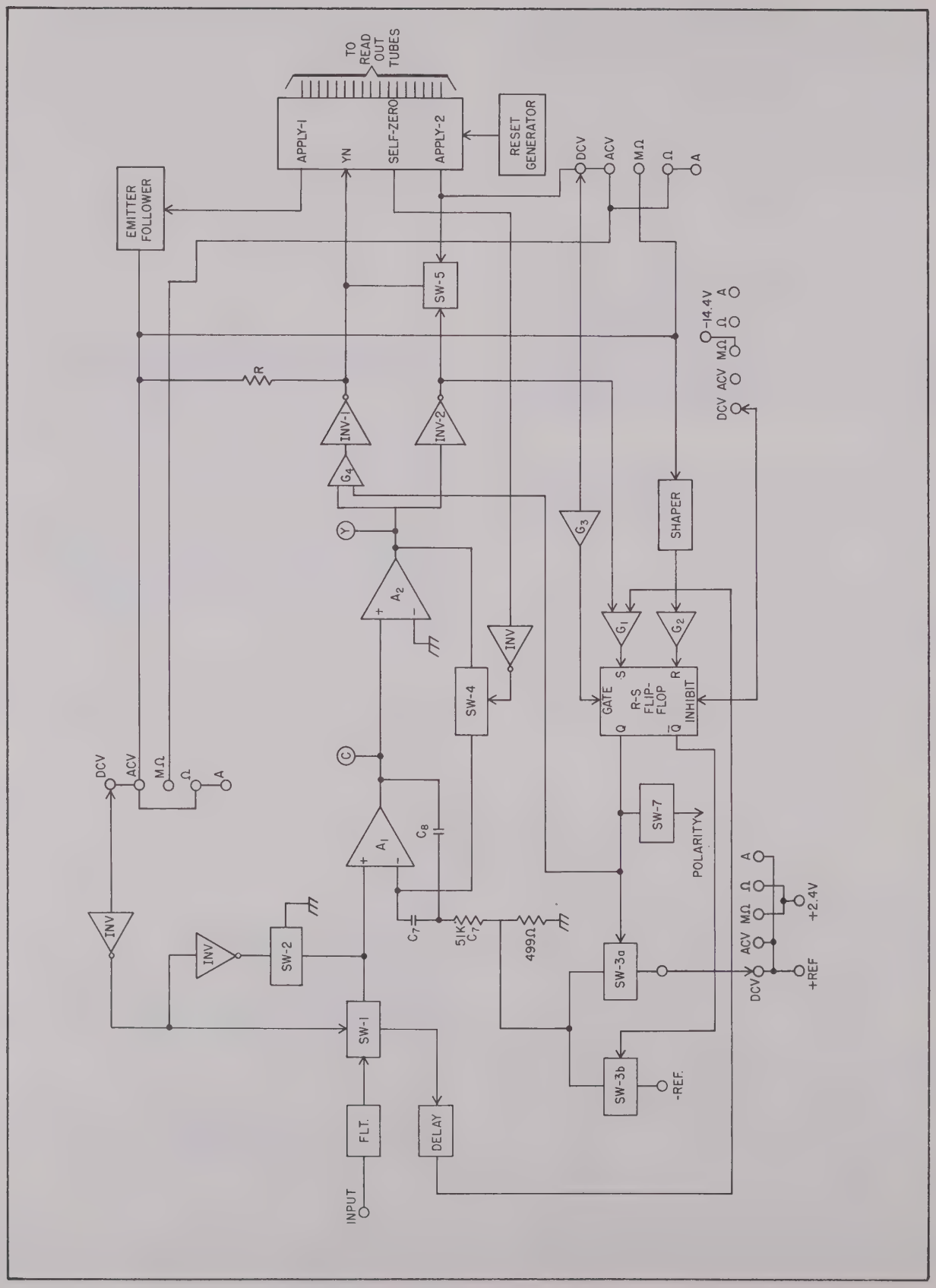


Figure 5. Complete Block Diagram

bipolar inverters. When SW-1 is on and SW-2 is off, the input voltage is applied to the integrator. When SW-1 is off and SW-2 is on, the integrator is returned to ground.

SW-3a and SW-3b

The SW-3a and SW-3b are reference switches and are controlled by a flip-flop which is set according to input polarity. These switches are junction FETs Q18 and Q19.

Flip-flop

This is a controlled R-S flip-flop. The inputs are driven by Apply-1 and the polarity sensing circuitry. The flip-flop also has provisions for inhibit and output gating.

Reference Voltages

The negative reference voltage is generated by a temperature compensated zener, CR10, and constant current supply. This combination produces a reference voltage that is highly stable with very little or no effects from temperature or supply voltage. The plus reference is derived from this stable negative reference through use of a unity-gain inverting amplifier consisting of Q47 and Q48. Q47 is a matched differential pair to minimize temperature effects and the amplifier is compensated for variation in supply voltage.

The reference zener is only switched on when it is applied to the integrator to minimize power consumption.

Amplifier A_1

A_1 is the integrating amplifier described in Theory of Operation, Section V. This amplifier consists of a FET input differential stage, Q6 and Q11, which provides the necessary high input impedance, a bipolar differential stage, Q7 and Q10, and a bipolar inverting amplifier, Q9. The amplifier gain is high (approximately 10,000) to reduce the total conversion error to less than 0.1%. The input FET stage is operated at approximately 0.5mA per section supplied from a constant current source, Q8, with common mode feedback.

Amplifier A_2

A_2 is a high gain differential amplifier that serves as a zero crossing detector or comparator. Its function is to indicate when the integrator output ramp crosses zero volts or the voltage from which it started. The amplifier consists of two bipolar diffential stages, Q15 and Q17, Q14 and Q16. The high gain of A_2 makes it sensitive to ramps produced by inputs down to 50 u V; consequently, the system is able to make accurate measurements with 100 u V resolution. The output of A_2 ultimately controls the oscillator from which the display (N_x) is obtained.

Inverter 1 and Inverter 2

Inverter 1 and Inverter 2 sense the output of A_2. This output is positive for positive inputs and negative for negative inputs. The oscillator (in MOS-IC) is controlled by the YN input. The oscillator is ON when this input is low and OFF when this input is high. Therefore, Inverters 1 and 2, Q22 and Q26, sense the polarity and control the oscillator through YN. Inverter 1 senses positive polarity and is gated such that it may not control YN when the polarity is negative. Inverter 2 senses negative polarity and sets the flip-flop for negative polarity. Inverter 2 controls the oscillator through YN via SW-5.

SW-5

SW-5 consists of bipolar transistors Q28 and Q29. SW-5 is discussed under Megohms Operation, Section VII. It allows Inverter 2 to control the oscillator only when MOS-IC Apply-2 output is low.

Reset Generator

The reset pulse is generated by a multivibrator with a high on-off ratio. The reset pulse is approximately 50 u s wide and occurs every 1.1 seconds. Transistors Q36 and Q37 form the multivibrator; R60 and C18 determine the rate; R62 and C17 determine the pulse width.

AC DC Converter

The ac/dc converter consists of a triple cascode FET follower coupled with an operational amplifier and hot carrier diode rectifiers. Transistor Q40 serves as a current source with negative dc feedback to stabilize the dc operating point of the operational amplifier Z1. The input FET, Q39, is bootstrapped via Q38 and C33, which feeds back a signal of the same phase and amplitude as the input signal. This unique configuration provides maximum input resistance and minimizes input capacitance, thus allowing use of a pure capacitive input divider. Frequency response of the ac system is specified from 22 Hz to 100kHz and has a constant input impedance of $\approx$ 200 pF.

Hot carrier diodes CR5 and CR6 form a full wave rectification circuit. The output is taken from one side of this circuit and is proportional to the average of the input signal. This signal is filtered and calibrated such that the dc output is proportional to the rms value of the input signal (for pure sine-waves).

Resistors R87, R88 and R89 determine the closed loop gain of the converter. The two half wave rectified signals are reconstructed at the junction of these three resistors and fed to the input of the amplifier. This closed loop contains the amplifier, ac coupling capacitor, and rectifier diodes, thus minimizing errors due to capacitor reactance or diode forward voltage drop and recovery time.

Components C31, R103, R133 and R132 provide input overload protection of 250V on the 100 mV range and 1000V on all other ranges.

Regulator

Transistor Q50 and Q51, and diode CR10 comprise a voltage regulator that maintains a constant 26.9V across the MOS-IC. This regulated voltage minimizes oscillator frequency drift.

Battery Charging Circuit

The charging circuit is designed to recharge the + 14.4 volt, -14.4 volt and 1.25 volt nickel-cadmium batteries. The circuit consists of a transformer, half wave rectifier and filter with current limiting resistors.

Charging time for completely discharged batteries is approximately 16 hours. The multimeter may be operated during recharge, in which case the charging circuit is charging the batteries at 30% of capacity.

SW-7

SW-7 controls the polarity sign. Transistor Q34 monitors the state of the flip-flop. When the flip-flop is set to apply a positive reference, + polarity, Test Point J goes to zero volts and Q34 is turned on, turning Q33 on, thus lighting the vertical segment. The horizontal segment is on for both polarities and indicates negative polarity when Q34 and Q33 are off.

MOS-IC

The MOS-Integrated Circuit Z2 is designed specifically for this equipment. It contains an oscillator, three-stage counter, seven-segment decoder driver and additional gating circuits to control the sequence of events in the multimeter. The output waveforms are shown in figures 9 and 10. The sequence is discussed in the Functional Operation, Section VII.

The MOS-IC is a 36-pin dual in-line package. It is compact and consumes very little power, enabling the multimeter to operate for long periods of time before battery recharge is necessary.

SECTION VII
FUNCTIONAL OPERATION

The multimeter is basically a dc voltmeter with a full scale sensitivity of 100 mV at the input terminals or probes. Series and shunt resistors are switched in or out of the circuit to accomplish range changes and an ac/dc converter is switched in to permit ac measurements. Otherwise, the basic operation of the instrument is identical on all ranges and functions except megohms. The operation of the megohms measuring circuitry is described later in this section.

Table 3 lists the state of various switching functions during the three segments of the measurement sequence. These three segments are self-zero and display, count to 1000 or ramp by E_{in}, and count $N_X = \frac{E_{in}}{E_R}$ (1000) or ramp by ER.

POSITIVE DC VOLTS

Referring to the complete block diagram, figure 5, integrator output waveform, figure 4, and the sequential event chart, table 3, consider the system to be in the self-zero mode. At this time, SW-4 is closed, connecting the output of A_2 to the inverting input of A_1. This forms a closed loop self-zeroing system in which amplifier offsets are automatically adjusted by placing the necessary offset voltage on C7.

Apply - 1 and Apply - 2 are off at a level of + 10V setting:

SW-1 off	-removing E_{in}
SW-2 on	-grounding the integrator input
SW-3a, b off	-removing E_R
SW-4 on	-self-zeroing

1. The next event is the generation of the reset pulse. The reset is self-generating and does not depend on other events. When the MOS-IC receives a reset pulse the following occurs:

a. MOS counters reset to 000.

b. Apply -1 turns ON (-14V).

(1) YN turns on (0V)

(2) SW-1 on; SW-2, SW-4 off

E_{in} is positive and is applied to the input of A_1 via SW-1. The output of A_1 begins ramping positive with a slope determined by E_{in}. The oscillator is running, being turned on by YN, and the MOS counters are counting the oscillator cycles. YN is held on by Apply -1 such that with zero volts in and consequently no ramp, the integrator remains on for 1000 counts.

OPERATING MODE	INTE-GRATOR INPUT	APPLY -1	APPLY -2	SELF-ZERO	SW-1	SW-2	FLIP-FLOP		INTEGRATOR		COM-PARATOR OUTPUT	SW-5	YN	NOTES	
							SW-3a	SW-3b	SLOPE	POLARITY					
SELF-ZERO AND DISPLAY	GND.	OFF (+10V)	OFF (+10V)	ON (- 14V)	OFF (-14V)	ON (0V)	OFF (-14V)	OFF (-14V)	0	0	0±.4V	OFF	OFF (+10V)	POSITIVE INPUT	
RESET															
COUNT TO 1000	$+E_{in}$	ON (-14V)	OFF (+10V)	OFF (+10V)	ON (0V)	OFF (-14V)	OFF (-14V)	OFF (-14V)	+	+	+	OFF	ON (0V)		RAMP + $B_y + E_{in}$
MOS-SWITCH															
COUNT TO N_x	GND.	OFF (+10V)	ON (-14V)	OFF (+10V)	OFF (-14V)	ON (0V)	ON (0V)	OFF (-14V)	-	+	+	OFF	ON (0V)		RAMP - $B_y + E_r$
ZERO-CROSS															
	SELF-ZERO AND DISPLAY N_x (SELF-ZERO MODE)														
	SELF-ZERO AND DISPLAY N_x (SELF-ZERO MODE)													NEGATIVE INPUT	
RESET															
COUNT TO 1000	$-E_{in}$	ON (-14V)	OFF (+10V)	OFF (+10V)	ON (0V)	OFF (-14V)	OFF (-14V)	OFF (-14V)	-	-	-	OFF	ON (0V)		RAMP - $B_y - E_{in}$
MOS-SWITCH															
COUNT TO N_x	GND.	OFF (+10V)	ON (-14V)	OFF (+10V)	OFF (-14V)	ON (0V)	OFF (-14V)	ON (0V)	+	-	-	ON	ON (0V)		RAMP + $B_y - E_r$
ZERO-CROSS															
	SELF ZERO AND DISPLAY N_x (SELF-ZERO MODE)														
	SELF-ZERO AND DISPLAY N_x (SELF-ZERO MODE)													MEGOHMS OPERATION	
RESET															
COUNT TO 1000	GND.	ON (-14V)	OFF (+10V)	OFF (+10V)	OFF (-14V)	ON (0V)	ON (0V)	OFF (-14V)	-	-	-	OFF	ON (0V)		RAMP - $B_y + E_r = \frac{R_f}{R_f + R_{cal}}(2.4V)$
MOS-SWITCH															
COUNT TO N_x	$+E_{in}$	OFF (+10V)	ON (-14V)	OFF (+10V)	ON (0V)	OFF (-14V)	OFF (-14V)	OFF (-14V)	+	-	-	ON	ON (0V)		RAMP + $B_y + E_{in} = \frac{R_b}{R_b + R_x}(2.4V)$
ZERO-CROSS															
	SELF-ZERO AND DISPLAY N_x (SELF ZERO MODE)														

NOTE: (1) Voltages in parenthesis are Input or Output Drive Signal Levels.
(2) AC Volts, AC + DC Current and Ohms Operations Identical to Positive Input.

Table 3. Sequential Event Chart

2. The counter reaches a count of 1000 at which time an internal overspill pulse generates the following events:

a. Counter reset to 000.

b. Apply -1 turns off (+10V).

(1) SW-1 off.

(2) SW-2 on.

(3) Flip-flop automatically set to positive polarity via gate G2.

c. Apply -2 turns on (-14V).

(1) Flip-flop output gated to SW-3a and SW-3b.

(a) SW-3a on.

(b) Gate G4 and Inverter -1 on.

$+E_R$ is applied to the integrator. The output steps negative by the magnitude of E_{in} and then ramps negative with a slope determined by $+E_R$. YN is held on by Inverter -2, allowing the oscillator to run.

3. When the Integrator output ramp crosses the zero reference, the output of A_2 turns off (0V) and Inverter -1 turns YN off (+ 10V). The following events take place when YN turns off:

a. Oscillator stops (inhibited by YN).

b. Apply -2 turns off (+ 10V).

(1) Flip-flop outputs off.

(a) SW-3a and SW-3b off.

c. Self-zero turns on.

(1) SW-4 on.

The counters now display the number of cycles that occurred during the ramp down or N_X as defined in equation (10), Section V. The system is returned to the self-zero mode and remains in that state until the next reset pulse occurs.

The count to 1000, time (T_1), is approximately 100 ms. The time for N_X pulses (T_2) is 100 ms for full scale and 200 ms for twice full scale.

The display time will be approximately 1.1 second minus the integration time or approximately 0.9 seconds for full scale readings.

NEGATIVE DC VOLTS

The operation for negative dc volts is very similar to positive dc volts. The three segments of the sequence remain identical. However, YN is controlled by Inverter -2 rather than Inverter -1; the flip-flop is set to apply a negative reference and indicate negative polarity on the display.

When E_{in} is applied to the amplifier via SW-1, the output steps negative by a magnitude of E_{in} and then ramps negative. At the end of T_1, 1000 counts, Apply -1 turns off and Apply-2 turns on. Apply-1 turns SW-1 off, SW-2 on and sets the flip-flop to positive polarity. The delay network connected to SW-1 opens gate G1 for several microseconds at the end of T_1, thus allowing Inverter-2 to switch the flip-flop to negative polarity. Since the ramp is negative, the output of A_2 will be negative and Inverter -2 will be on, setting the flip-flop to apply a negative reference. The negative reference then causes the output of A_1 to ramp positive toward zero volts.

At zero crossing, end of T_2, YN is turned off via A_2, Inverter-2 and SW-5, thus stopping the oscillator and displaying the number N_X.

OHMS OPERATION

In order to measure resistance, the multimeter applies a constant current to the resistor to be measured (R_X) and then measures the dc voltage dropped across the resistor.

As shown in the Simplified Switching Diagram, figure 6, 2.4 volts is applied to the OHMS probe through resistor R_b. Resistor R_b is 100 times the full scale resistance value to reduce non-linearity in the current generator. This, coupled with the reference calibration, reduces the ohmmeter error to less than 0.3% of full scale.

The block diagram for ohms operation is shown in figure 7. System operation and switching are the same as described for +dc volts.

When an unknown resistor is placed across the OHMS probe and common, a voltage is developed at the input of the system as determined by R_b, R_X, and the + 2.4V supply. This voltage will be:

$$E_{in} = \frac{R_X}{R_X + R_b} \quad (2.4) \qquad (11)$$

This voltage, when applied to the integrator through SW-1, will produce a positive ramp as described in + dc volts operation.

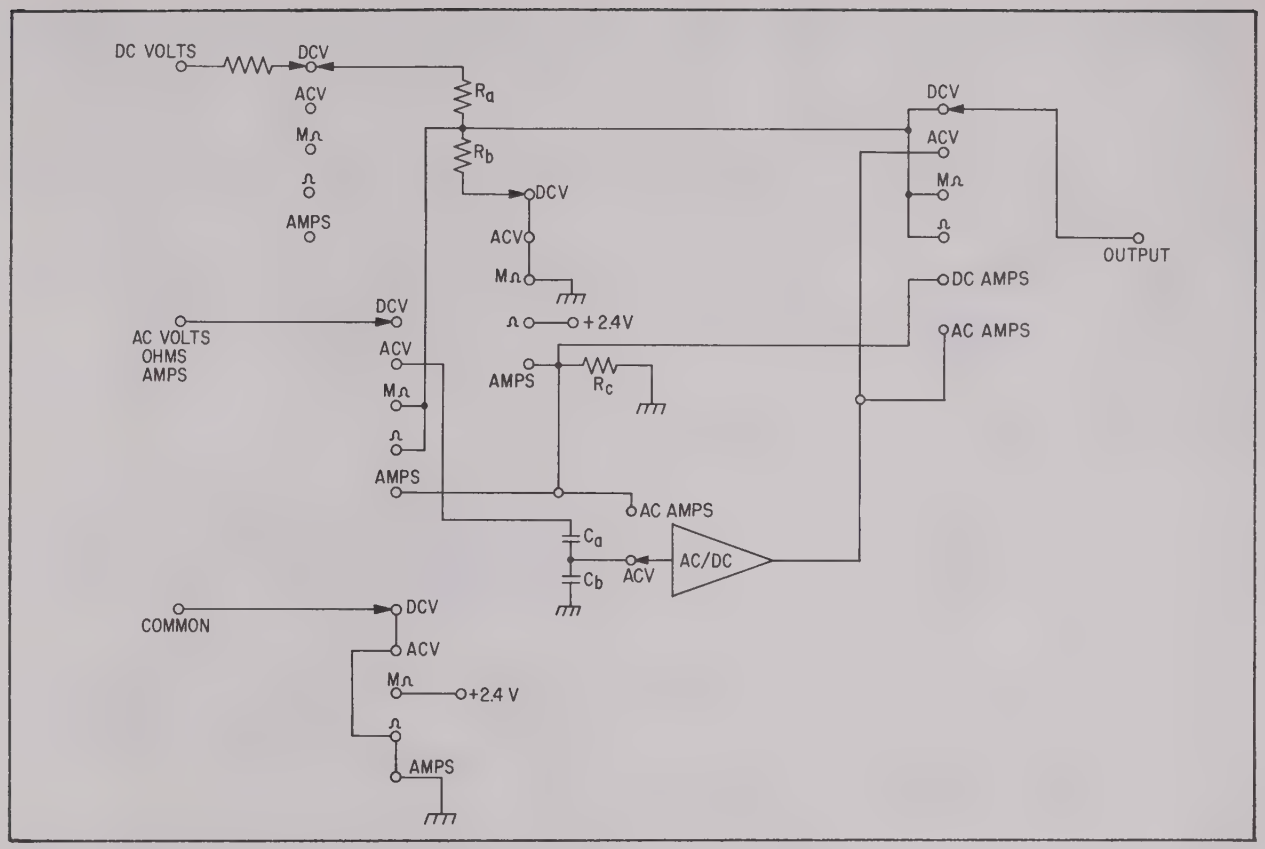


Figure 6. Simplified Switching Diagram

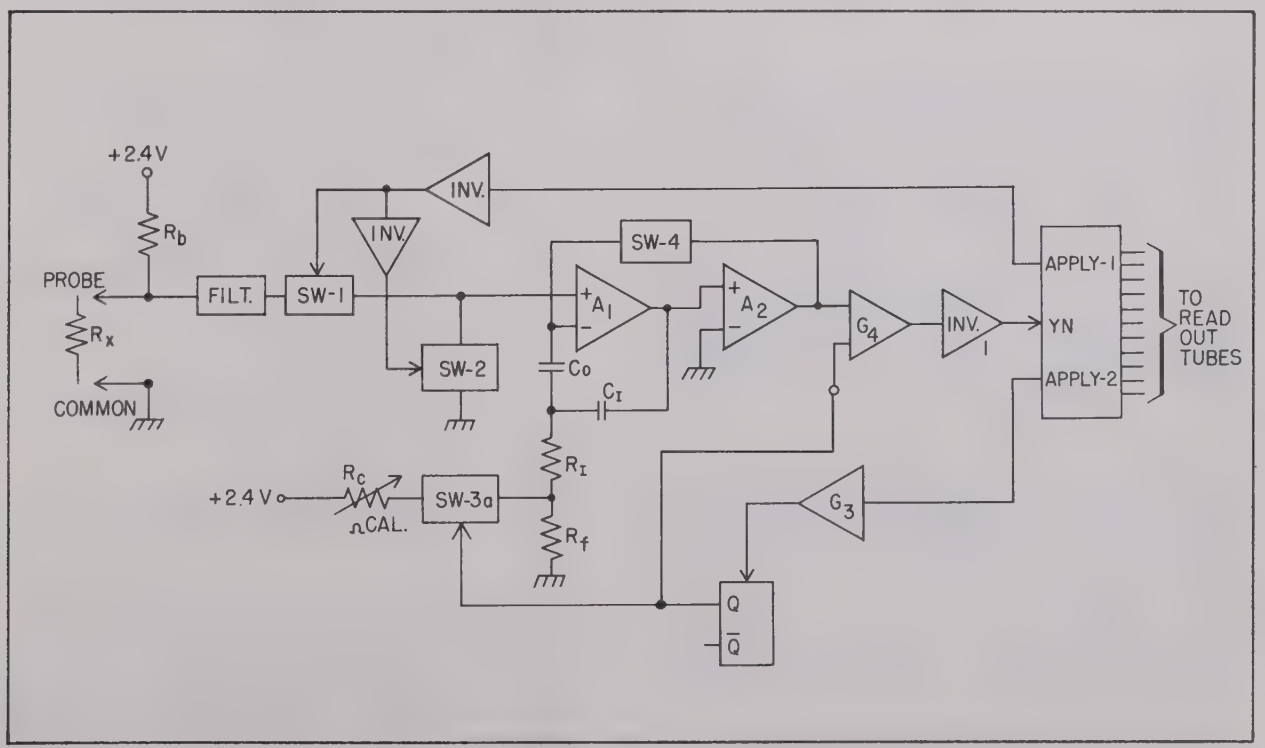


Figure 7. Ohms Block Diagram

From Theory of Operation, the digital display obtained from this input will be:

$$N_x = \frac{E_{in}}{E_R} (1000) \quad (10)$$

However, E_{in} is now expressed by equation (11) and E_R is determined by the voltage division of R_{cal} and R_f.

Therefore:

$$E_R = \frac{R_f}{R_f + R_c} (2.4) \quad (12)$$

Substituting equation (11) and (12) into equation (10):

$$N_x = \frac{\frac{R_x}{R_x + R_b} (2.4)}{\frac{R_f}{R_f + R_c} (2.4)} (1000)$$

Simplifying:

$$N_x = \left(\frac{R_x}{R_x + R_b}\right) \left(\frac{R_f + R_c}{R_f}\right) (1000) \quad (13)$$

The term $\frac{R_f + R_c}{R_f}$ is a constant and is adjusted in calibration to be approximately equal to 100. Therefore:

$$N_x = \frac{R_x}{R_x + R_b} (100,000) \quad (14)$$

N_x is proportional to the resistive divider formed by R_x and R_b. If R_b is large in respect to R_x then N_x is directly proportional to R_x. At full scale

$$\frac{R_x}{R_x + R_b} = \frac{1}{1+100} = \frac{1}{101}.$$

It should be noted that the ohmmeter supply voltage (+2.4V) has no effect on the ohmmeter accuracy since it is used for both input divide supply and reference supply.

MEGOHMS OPERATION

The multimeter has been designed to make resistance measurements up to 199.9 megohms. This is accomplished by measuring $\frac{1}{R}$ and displaying the reciprocal of that measurement.

The block diagram for megohms operation is shown in figure 8.

Significant differences between the Megohms and Ohms circuitry are:

1. The input resistive divide consisting of R_x and R_b is inverted.

2. The reference voltage is applied to the integrator during T_1. The R-S flip-flop is set to apply a positive reference by locking it in a positive state.

As shown in the simplified switching diagram, figure 6, + 2.4 volts is applied to the COMMON lead. R_b is connected between the OHMS probe and ground.

When an unknown resistor is placed across the OHMS probe and COMMON, a voltage is developed at the input or at SW-1. This voltage will be:

$$E_{in} = \frac{R_b}{R_x + R_b} (2.4V) \quad (15)$$

This voltage is not applied to the integrator until Apply-2 occurs (Time T_2). When the reset occurs, Apply-1, via gate G3 and the flip-flop, applies a positive reference voltage to the integrator. This voltage produces a negative going ramp for the time period T_1 or 1000 counts.

At the end of 1000 counts Apply-1 turns off and Apply-2 turns on. This removes the reference voltage and applies the input voltage, producing a ramp with positive slope so the output of A_1 begins ramping back toward zero volts.

When the ramp crosses zero volts, A_2 switches to zero and Inverter-2, via SW-5, switches YN off, stopping the oscillator. SW-5 is then turned off as Apply-2 turns off and the system switches to self-zero mode and displays the number of cycles that occurred during time T_2.

The output voltage change of A_1 during T_1 (ramp down by + E_R) will be:

$$V_{out} = \frac{E_R}{R_T C_I} \left(\frac{1000}{f}\right) \quad (16)$$

Where:

$$E_R = \frac{R_f}{R_f + R_c} (2.4V) \quad (17)$$

Therefore:

$$V_{out} = \frac{\frac{R_f}{R_f + R_c}}{R_T C_I} \left(\frac{1000}{f}\right) (2.4V) \quad (18)$$

The output voltage change of A_1 during T_2 (ramp up by + E_{in}) will be:

$$V_{out} = + \frac{E_{in}}{R_T C_I} \left(\frac{N_x}{f}\right) + E_{in} \quad (19)$$

where E_{in} is expressed in equation (15).

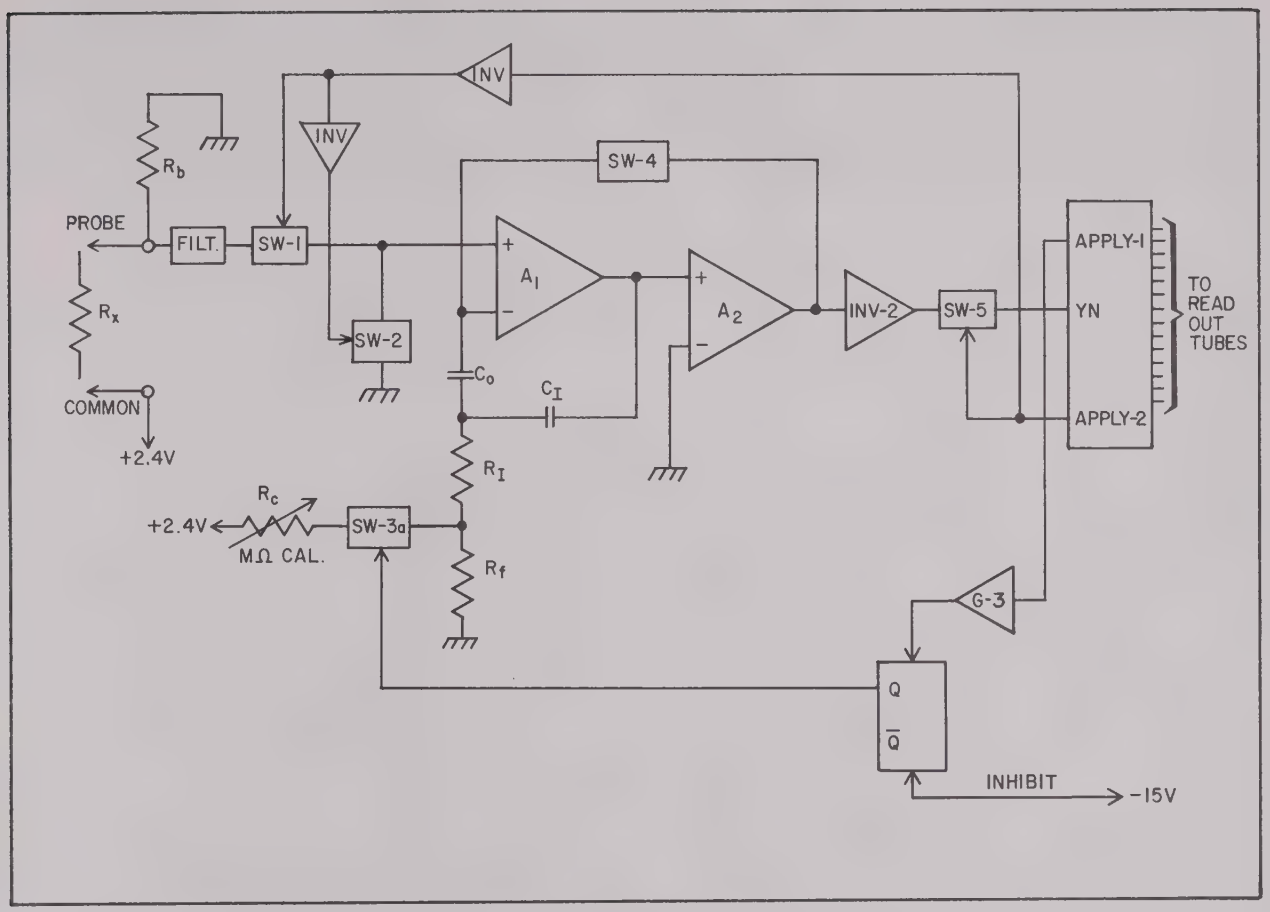


Figure 8. Megohms Block Diagram

Equating equation (18) and (19):

$$\left(\frac{R_f}{R_f R_C}\right)\left(\frac{1}{R_T C_I f}\right)\left(1000\right)\left(2.4\right) = \left(\frac{R_b}{R_x+R_b}\right)\left(\frac{1}{R_T C_I f}\right)\left(N_x\right)\left(2.4\right) + \left(\frac{R_b}{R_x+R_b}\right)\left(2.4\right)$$

Therefore:

$$N_x = \left(\frac{R_f}{R_f R_c}\right)\left(\frac{R_x+R_b}{R_b}\right) 1000 - R_T C_I f \qquad (20)$$

The term $\frac{R_f}{R_f+R_c}$ is a constant and is adjusted in calibration to be 1/100.

Equation (20) is of the same form as the equation for the ohms reading with the exception of the term $-R_T C_I f$. For the megohms ranges R_T is adjusted such that this term is equal to 10 and exactly compensates for the non-linearity in the input resistive divide. Therefore, the megohms ranges are linear and may be used up to twice full scale.

Significantly, if R_x is zero ohms, i.e., OHMS probe and COMMON connected together, then $\frac{R_x + R_b}{R_b}$ is equal to one and N_x is equal to zero. Functionally, E_R is applied to the integrator for 1000 counts, E_{in} is then switched to the integrator (E_{in} is now equal to the ohmmeter supply voltage, +2.4V); in order to balance the inputs to the integrator the output steps positive by the amount of E_{in}, or 2.4V. From equation (18), if $R_T C_I f$ is equal to 10 then V_{out} at T_1 is equal to -2.4V and the application of E_{in} drives the integrator output back to zero, shutting off A_2 and ultimately YN to display a reading of 000.

AC VOLTS AND CURRENT OPERATION

In ac volts and current the ac/dc converter is used to convert the input signal to a dc voltage. This dc voltage is then displayed as any other dc voltage, except that the polarity indicator is turned off. The converter output is positive and is calibrated such that the + dc reference can be used.

The ACV probe is connected to a calibrated capacitive divider which is switched for full scale ranges of 100 mV to 1 kV.

AC current is measured by monitoring the voltage across the shunt resistors and converting this ac signal to a dc voltage via the 100 mV AC VOLTS range.

DC CURRENT OPERATION

In dc current measurements, shunt resistors are switched across the input leads. The voltage dropped across these shunts is monitored and displayed identical to the dc voltage reading. Polarity is automatically indicated as discussed under SW-7.

Since the basic analog conversion is designed to display 100.0 mV for 90.909 mV input, a fixed resistor, R99, is switched across R29 in all positions except DC AMPS. This changes the system from 90.909 mV to 100.0 mV sensitivity. This increases the resistor R_f in dc current mode, to produce an exact 100.0 mV reference supply.

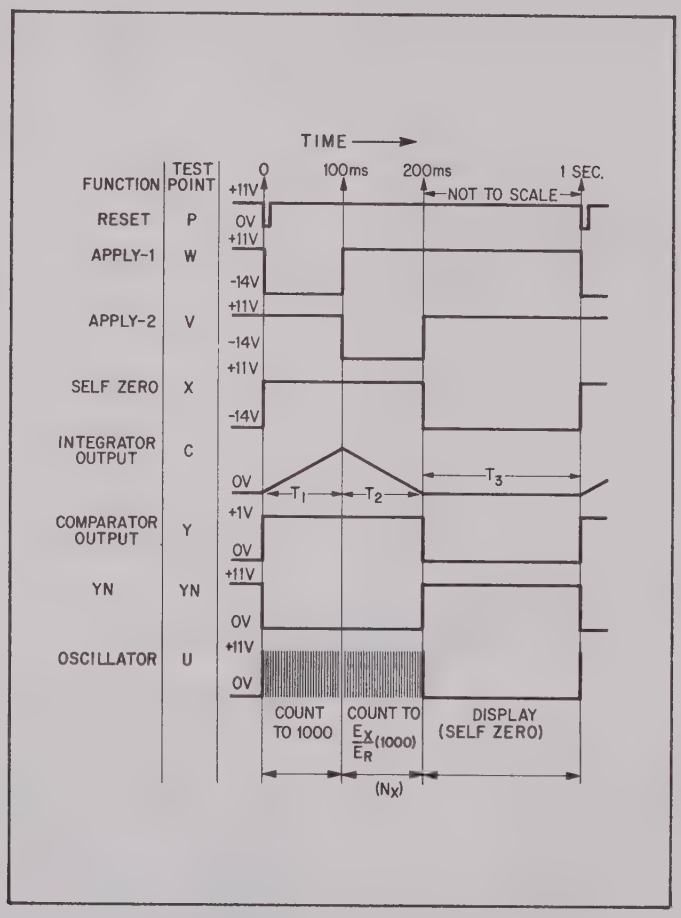
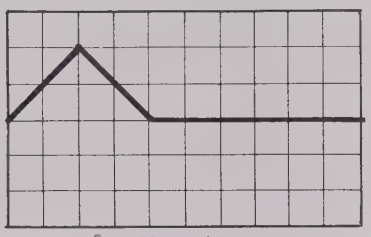


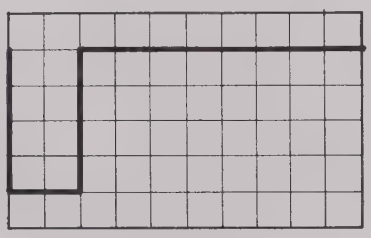
Figure 9. Waveforms - Model 3300

(a)



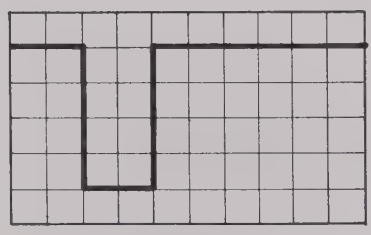
50 msec./div.
Integrator output (+fullscale)
Point – C

(b)



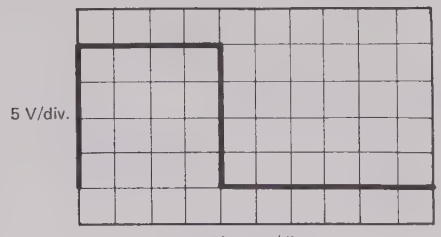
50 msec./div.
Apply – 1
Point – W

(c)



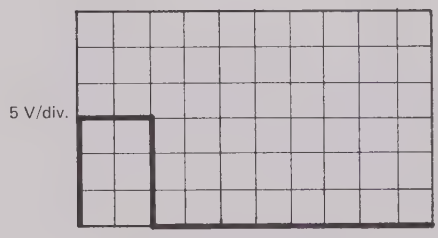
50 msec./div.
Apply – 2
Point – V

(d)



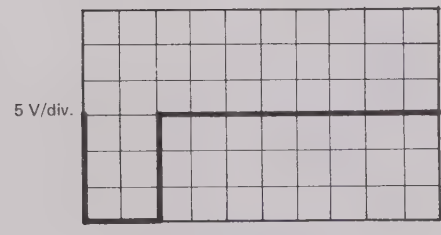
50 msec./div.
Self-Zero
Point – X

(e)



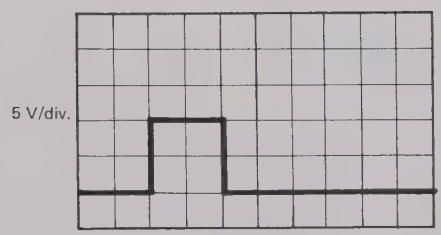
50 msec./div.
Series FET Gate (SW-1)
Point – AA

(f)



50 msec./div.
Shunt FET Gate (SW-2)
Point – A

(g)

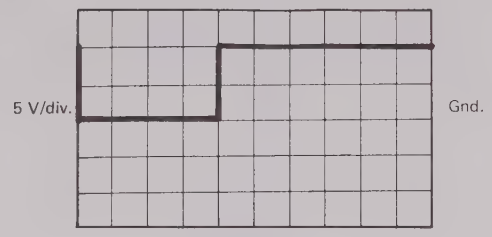


50 msec./div.
Flip-Flop Gating
Point – I

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point–W – Negative Trig. Slope – +100 MV input on 100 MV D.C. range unless otherwise specified.

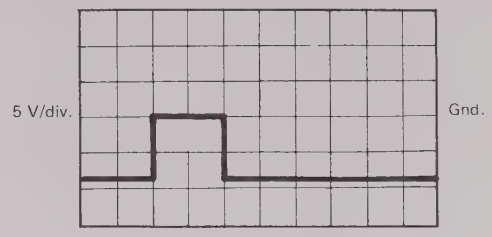
Figure 10. System Waveforms (Sheet 1 of 3)

(h)



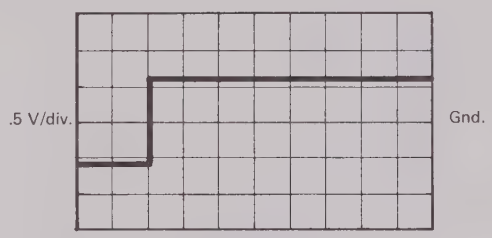
50 msec./div.
YN Signal
Point – YN

(k)



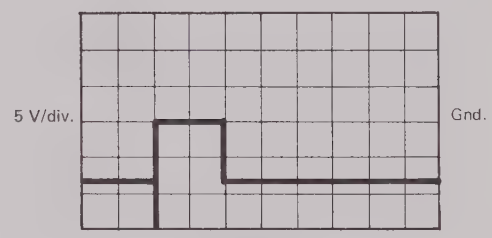
50 msec./div.
100 MV D.C. Range +100 MV Input
Point – J

(i)



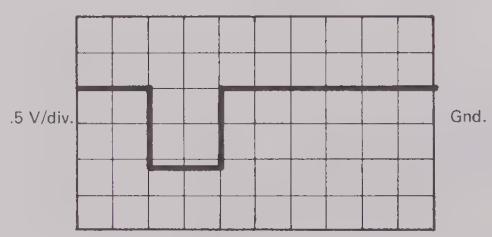
50 msec./div.
Base Q-1 (SW-1 Series FET Drive Switch)
Point – B

(l)



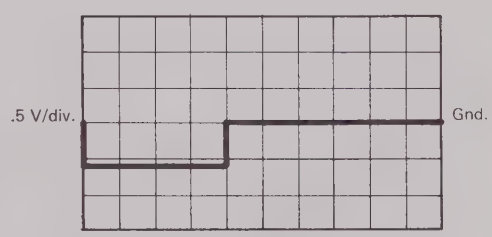
50 msec./div.
100 MV D.C. Range -100 MV Input
Point – JJ

(j)



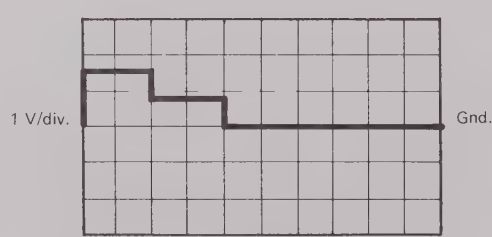
50 msec./div.
Base Q-44 (Flip-Flop Gating – Drive Signal)
Point – BB

(m)



50 msec./div.
100 MV D.C. Range -100 MV Input
Point – Y

(n)

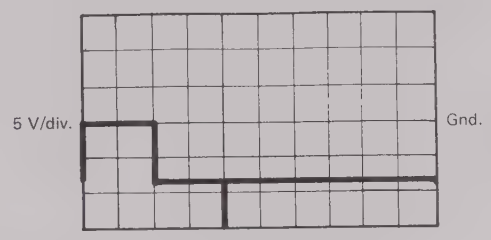


50 msec/div.
100 MV D.C. Range +100 MV Input
Point – Y

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point–W – Negative Trig. Slope – +100 MV input on 100MV D.C. range unless otherwise specified.

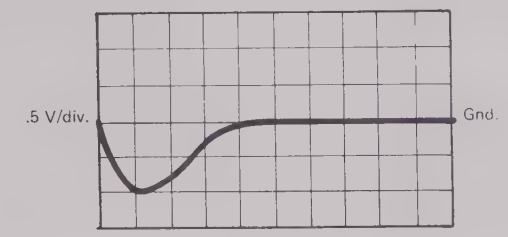
Figure 10. System Waveforms (Sheet 2 of 3)

(o)



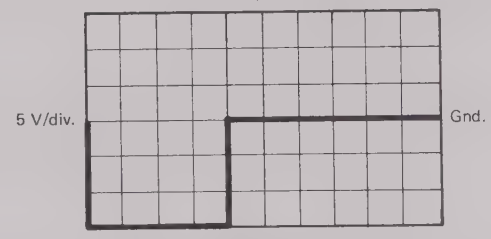
50 msec./div.
1 MΩ Range 1 MΩ Input
Point — J

(r)



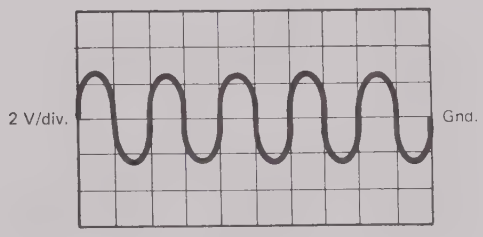
10 usec./div.
Flip-Flop (-Gating Signal)
Point — H
Sync T.P;W, † Slope

(p)



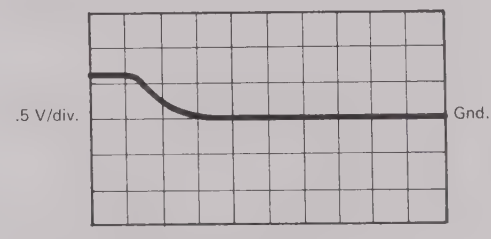
50 msec./div.
Self-Zero FET Gate
Point — D

(s)



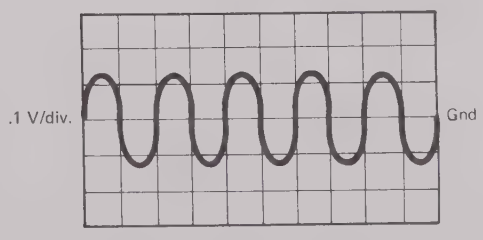
.5 msec./div.
AC/DC Converter (Z-1 Output)
Point — O
Sync Internal

(q)



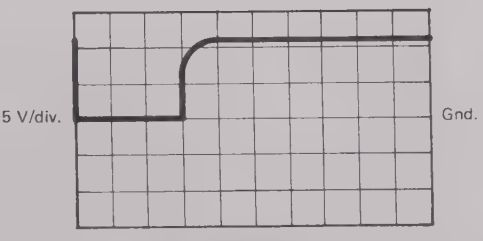
10 usec./div.
Flip-Flop (Positive Polarity Set Signal)
Point — HH
Sync T.P.W, + Slope

(t)



.5 msec./div.
AC/DC Converter (Feedback)
Point — SS

(u)



20 usec./div.
Reset Pulse
Point — P

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point—W — Negative Trig. Slope — +100 MV input on 100 MV D.C. range unless otherwise specified.

Figure 10. System Waveforms (Sheet 3 of 3)

SECTION VIII
TROUBLESHOOTING

Servicing can be most conveniently carried out by removing the back and the four screws that secure the chassis to the case. The case can then be removed, providing access to the PC boards. It is advisable to pinpoint the trouble before disassembling the two PC boards.

Refer to figures 11 through 16 for the location of any part or test point.

RECOMMENDED EQUIPMENT

1. DC Standard and Differential Voltmeter (Hewlett-Packard Model 740B).

2. Hickok Model 5002 Oscilloscope with two 10:1 Probes (Hickok Style 100-155).

3. DC Microvoltmeter and AC Voltmeter (Hickok Models DP110 and DP130 with Model 3202 Digital Main Frame).

4. Sine Wave Oscillator (Krohn-Hite Model 4200).

TROUBLESHOOTING

The circuitry is divided into the following sections:

1. MOS outputs and readouts.

2. Integrator.

3. Comparator.

4. Input and self-zero FETs switching.

5. Reference FET switching and flip-flop.

6. Output circuitry and YN.

7. AC/DC converter.

8. Function and range switching.

9. DC voltage regulators and reset pulse circuitry.

10. Charging circuit.

1. MOS Integrated Circuit Z2 Outputs and Readouts

a. The MOS-IC outputs are connected to the tubes and are checked by observing the segments of each individual tube.

b. If there is no count-display cycle, refer to Paragraph 9 of this section for reset pulse problems.

c. If any one of the bars does not light, turn unit off and inspect connections from MOS-IC to sockets.

d. The oscillator-multivibrator is inside the MOS-IC package. Check for faulty components or connection of R57, R58, C15 and C16. (The oscillator is on during the count cycle and could be checked as follows:

(1) Connect the trigger input of the scope to point W, using a 10:1 probe.

(2) Set trigger to external, mode to AC-HF, slope to "-".

(3) Set TIME/DIV to 50 u s, VOLTS/DIV to 0.5V.

(4) Connect vertical input to point U, using a 10:1 probe. The wave form should be a square wave 100 u s/cycle.

e. The voltage at point R measured in reference to -14.4V should be 26.9 ± 0.1V. If this voltage is not correct, refer to Section IX for voltage regulator problems.

f. Apply 100 mV dc input on the 100 mV range, observe and correct as follows:

Test Point	Test Value	Corrective Action
W	Figure 10b	Check Q32 and associated circuitry
V	Figure 10c	Check Q44, CR8 and associated circuitry
X	Figure 10	Check R18 and R19

Also, with zero input, Apply - 2 is on (-11 volts) for less than 50 u s. (Apply - 2 is the time for which a dc reference voltage is being applied to the integrator to bring the ramp to zero level, and with zero input the ramp should be zero volts.) If the ramp is not zero, C1 should be readjusted per calibration procedure, or input FETs checked for leakage.

g. Out -2 (pin 33) is the oeverrange output from the MOS-IC package. This output is always -14.4V until the count exceeds 2000; at that instant it switches to + 11V and holds until the reset pulse occurs. Check this output at point Z with an input of 250 mV on the 100 mV range. (Scope setup is as in paragraphs 1d(1) and 1d(2), VOLTS/DIV 0.5V.

h. Out-3 (pin 29) is the full-scale output which turns the "1" bars of the first tube on (numbering from left to right). This is no access to this pin when the unit is assembled, since it is tied directly to the tube socket. If the "1" does not light when the input exceeds 1000 count (equivalent to 100 mV input on the 100 mV range), turn unit off, disassemble the boards from their mounting position and check the connection to the socket and the socket pin connection to the tube. If that does not solve the problem, make sure that YN is on (ground potential) for more than twice the time Apply-1 is on (refer to figure 10 for wave form). If YN checks correctly and the "1" bar does not light, the MOS package or tube should be changed.

The negative sign indicator is tied to the +11V on dc volts and dc amps via the range switch. Check connection in case of failure. For positive indicator problems check Q33 and Q34 and associated circuitry.

i. The output drivers from the MOS-IC package to the seven-segment tubes can be damaged only by the following:

(1) A short across the output connection of the MOS-IC package.

(2) The outputs might be working but the connections to the tube sockets are not making contact. (During the display cycle, and for a lighted bar, the output from the MOS-IC package is + 11V.)

(3) The outputs might have internal leakage such that the bar does not turn off completely. Replace MOS-IC.

2. Integrator Check

a. With the function switch set to DC VOLTS, range switch set to 100 mV, short the dc probe to COMMON.

b. Set the scope as follows:

(1) Connect trigger input to point W, using a 10:1 probe.

(2) Set TIME/DIV to 50 ms, VOLTS/DIV to 0.1V.

(3) Set scope on EXT. trigger, mode to AC-LF, slope to "-".

(4) Connect vertical input to test point C, using a 10:1 probe. Observe no ramp and dc level is 0. ± 0.5V.

c. If the above dc level is not as stated, check the following test values at the indicated points:

Test Point	Test Value		Corrective Action
±14.V supply (E)	+13.2 to + 16.4V		Check battery connections to the boards
-14.4V supply (EE)	-13.2 to -16.4V		
(DD)	11.9 ± 1.0	Based on + 15.0V	Check Q10 and Q27
(CC)	7.0 + 1.0		Check Q8
(C)	0 ± 0.5V	- 15.0V	Check Q9 and then Q6 and Q11

If the above values are correct, remove the input short and apply 100 mV. With the scope set up as in paragraphs 2b(1), 2b(2) and 2b(3) except VOLTS/DIV to 0.2V, observe a ramp at point C as shown in figure 10a.

If the ramp is not correct, refer to paragraphs 4 and 5 of this section for FET switching problems.

3. Comparator Check

a. With the same setup as in paragraph 2a, check the following test values at the indicated test points:

Test Point	Test Value		Corrective Action
(FF)	+ 12.5V ± 1.0	Based on + 15.0V	Check Q14 and Q16 and associated resistors
(F)	± 13.3 ± 1.0		
(G)	- 1.0 to -1.4V	-15.0V	Check Q15, Q17, CR2, CR3 and associated resistors

b. With a + 100 mV applied to the input oscilloscope (setup as in paragraphs 2b(1) and 2b(2), and 2b(3), observe a wave form at test point Y as shown in figure 10n.

If the waveform is not correct, refer to paragraphs 4 and 5 for FET switching problems.

4. Input and Self-zero Switching

a. With the scope set up as in paragraphs 2b(1), 2b(2), and 2b(3), check the test values at the indicated test points as follows:

Test Point	Test Value	Corrective Action
(A)	Figure 10	Check Q4 and Q5
(AA)	Figure 10	Check Q1 and Q2
(B)	Figure 10	Check Q1 and CR1

b. Self-zero switch:

Test Point	Test Value	Corrective Action
(D)	Figure 10	Check Q12 and Q13

5. Reference FET Switching and Flip-Flop (Megohms Operation)

The flip-flop drives the two reference FETs Q18 and Q19 for the application of + ER and -ER voltages to the integrator. There are three controlling signals going in the flip-flop, plus a gate from the output of the comparator which senses the polarity of the input.

If it is determined that a problem exists in this area, check the following test points:

For Positive Inputs		Corrective Action
(JJ)	-14.4V	Check Q20 and Q21
For Netative Inputs		**Corrective Action**
(J)	-14.4V	Check Q24 and Q25

The flip-flop outputs are at test points JJ and J. These test points may be checked as follows:

Test Point	Waveform/DC Level	Corrective Action
+ 100 mV input - on 100 mV dc range		
(JJ)	-14.4V	Q20, Q21
(J)	Figure 10K	Q24, Q25
-10 mV input - on 100 mV dc range		
(JJ)	Figure 10l	Q20, Q21
(J)	-14.4V	Q24, Q25, Q26, Q30

If the flip-flop is working properly, the switching FETs, Q18 and Q19, may be checked by monitoring the voltage at the drain and source. This voltage is the reference voltage which is present only during Apply-2 (except in megohms operation). The source voltage should be +90.9 mV during Apply-2 for positive inputs (Q19 on) and -90.9 mV during Apply-2 for negative inputs (Q18 on). The operation of the reference FET's and flip-flop is identical on all functions except megohms. In megohms the flip-flop is held in the positive polarity state by connecting point JJ to -14.4V via the range switch deck 2A rear. This allows only the positive reference FET, Q19, to be turned on when the output of the flip-flop is gated on via Q44. Apply-1 and Apply-2 are interchanged at points K and BB. The waveform at BB is shown in figure 10j for all functions except megohms. In megohms test point BB will be similar to figure 10i. This signal is generated by Apply-1 and applies the reference to the integrator during Apply-1 which generates a negative ramp at point C.

Test Point	Test Value	Corrective Action
(HH)	Figure 10q	Check Q20, R22 and C12
(H)	Figure 10r	Check Q30, R119 and C42
(I)	Figure 10g	Check Q44 and associated circuitry

For test point I, the time for which the voltage is around ground depends on the dc voltage being applied (with 10 kHz oscillator frequency, 100 mV input on 100 mV range, test point I is at ground for 100 ms).

6. Output Circuitry and YN

YN is the controlling input for the MOS package. When YN is around ground the count starts; YN is on. When YN is + 11 volts the count stops; YN is off. Any time YN is below ground more than -0.7V, replace CR4.

With a negative dc input voltage on the dc volts range the YN drive conditions are:

Q29 off during Apply-2; Q26 and Q28 will turn on when the comparator output is negative. Q22 and Q23 are off.

If the above does not prove to be true, check and correct as needed, so that the YN operation is exactly as above. See also Section V.

7. AC/DC Converter

The time constants in the ac/dc converter will hold the amplifier (A_1) in a saturated condition for several seconds after turn-on; however, if the input is shorted to ground and test point O is not at ground (± 1V), check the following test points and correct where needed:

Test Point	Test Value	Corrective Action
(L)	10V	Check Q43 and CR7
(M)	+15.0V	Connections
(MM)	-15.0V	Connections
(O)	0.0 ± 1V dc	Readjust R80 and check Q40
(LL)	+7.5V	Check Q38

If the R80 adjustment is not sufficient to bring point O to zero volts (allow time for stabilization) check Q38, Q39 and Q40. Make sure Q39 has the lowest I_{DSS}.

With 100 mV rms, 1.0 kHz input, observe the following test points:

Test Point	Test Value	Corrective Action
(SS)	Figure 10t	Check CR5 and CR6
(O)	Figure 10s	Check Z1

8. Function and Range Switching

Check connections carefully. Check for any switch deck that may have been damaged due to excessive current and voltages. Correct as needed. Check for component mountings and shorts.

9. DC Voltage Regulators and Reset Pulse Circuitry

a. For no reset pulse output at test point P, check Q36 and replace if damaged. If correct, replace Q37. Check test point R for + 11V.

b. Voltage regulators:

The battery voltages are allowed to discharge through normal operation from:

+ 16.7V to + 13.0V

-16.7V to -13.0V

Since it is essential to operate the MOS package at 26.9V, a voltage regulator referenced to the negative battery is used; the total voltage across the package is 26.9V ± 0.1V.

Check and correct as follows:

Test Point	Test Value (referenced to negative battery)	Corrective Action
(Q)	10.6 ± 10%	Replace CR13
(R)	26.9 ± 0.1V (adjusted by R126)	Replace Q50, check Q51

c. Reference Regulators:

The reference regulator is turned on for the duration of Apply-2 (during Apply-1) in megohms operation. To check the regulator, unsolder the end of R111 that ties to Apply-2 and connect to the negative supply through an additional 100K ohm resistor.

Check and correct as needed:

Test Point	Test Value	Corrective Action
Base of Q45	-0.7V	Check CR9 and Q45
(S)	-6.3V ± 5%	Check Q46, CR10 and Q49
(T)	+6.3V ± 5%	Check Q47, Q48

If Q45 does not turn on when connected to R111, check signal at base.

10. Charging Circuit

The transformers and rectifying circuit are always tied to the batteries. Check the diodes and replace if damaged. Check the power resistors and wiring. The BAT. CHK position on the function switch monitors the + 14.4 volt battery. If the charging circuit is functioning properly this reading should increase several digits per minute when the multimeter is plugged into the power line. The + 1.25V battery is charged through a separate transformer winding (terminals 6 and 7) and is not monitored. If it is determined that all voltages are correct except the 1.25V, check CR12 and R122.

SECTION IX
CALIBRATION

CLEANING PROCEDURE

If the unit to be calibrated has been serviced, it should be cleaned prior to calibration. Brush the circuit board clean of any rosin deposits, using clean "Printed Circuit Cleaner" manufactured by the John B. Moore Company. Dip the boards and switches into a tank of clean Freon TF or Genesolv D for a period of 20 seconds. Remove from this tank and dip immediately into a tank of Freon TF or Genesolv D with two parts of Dow Corning DC200 silicon oil added.

RECOMMENDED CALIBRATION EQUIPMENT

Hewlett-Packard 740B dc Standard and Differential Voltmeter

Hickok DP110 Microvoltmeter with Hickok Model 3202 Digital Main Frame.

Hickok DP130 ac Voltmeter calibrated for 100% overrange, with Hickok Model 3202 Main Frame.

Krohn-Hite Model 4200 Sine Wave Oscillator.

General Radio Model 1432P Resistor Standard Box, 10K Ohms, 10 Megohms, 0.05%.

DC Current Generator, capable of supplying 1 mA to A ± 0.02%.

Hickok Model 5000 or Model 5002 Oscilloscope.

CALIBRATION PROCEDURE

With the recommended calibration equipment, the multimeter inputs should be monitored to the given accuracy (unless the equipment being used is guaranteed to be within that accuracy). Ambient temperature should be 23°C ± 1°C.

1. Power Supply

Turn unit on. With the DP110 connected across test points R and EE, measure 26.9V ± 0.1V. Adjust R126 to read the above voltage if necessary.

2. Zero Adjust

a. Set function switch to OHMS, range switch to 100K range.

b. Connect multimeter to decade resistor box set to 1.00 KΩ .

c. Adjust C1 for a reading of 01.0 ± 00.0.

d. Set decade resistor to 1.06 KΩ and check display for 01.1. Readjust C1 if necessary.

e. Set decade resistor to 0.94 KΩ and check display for 00.9. Readjust C1 if necessary.

f. Repeat c, d and e to verify the setting of C1; readjust if necessary.

3. Ohms

a. Set function switch to OHMS and range switch to 10K range.

b. Connect multimeter to decade resistor set to 10.00 KΩ .

c. Adjust R101 for a display of 9.98 ± 0.00. (Note: full scale on ohms must be adjusted to 998 to center non-linearity of divider.)

d. Set range switch to 1M range and decade resistor to 1.000 MΩ .

e. Adjust R134 for a display of 1.000 ± 0.000.

f. Short probes to common and check for zero on all ranges. Allowable: 1 digit on current, ohms, dc volts; 2 digits on ac volts.

NOTE

If MOS-IC, R57-58, C15-16 or R14-15 have been changed for any reason, MΩ may not read zero with leads shorted.

Adjust R14 for MΩ zero as follows:

Function - OHMS

Range - 10 MΩ

(1) Short ohms probe to common; display 0.00 ± 0.00. If display is 0.01, change R14 (RX) to next higher standard value.

(2) Apply 19 KΩ to input; display 0.01 ± 0.00. If display is 0.00, change R14 (RX) to next lower standard value.

(3) Repeat (1) and (2) if R14 is changed.

4. DC Volts

a. Set function switch to DC VOLTS, range switch to 100 mV range.

b. Apply u 190.00 mV and adjust R97 to display u 190.0 ± 00.1.

c. Set range switch to 1V range and apply u 1.9000V. Adjust R67 to display 1.900 ± 0.001.

d. Repeat b and c as these adjustments are interacting.

e. Set range switch to 100 mV range and apply -190.00 mV. Adjust R105 to display -190.0 ± 00.1.

f. Check 10V, 100V and 1KV ranges to insure accuracy.

5. AC Volts

a. Set function switch to AC VOLTS, range switch to 100 mV.

b. Connect ACV probe to COMMON. With 10:1 scope probe connected to test point O, adjust R80 for a dc level of 0 ± 1V. (Allow time for stabilization.)

c. Calibrate individual ranges by the following table:

Range	Input Voltage 2.5 Khz	Adjust
100mV	190.0mV	R94
1V	1.900V	C22
10V	19.00V	C23
100V	190.0V	C24
1KV	1.000KV	C25

d. Check all ranges for proper accuracy (refer to Section II) at 22 Hz, 50 Hz and 100 kHz. Maximum input frequency on 1KV range is 10 kHz.

6. Current

There is no current calibration. However, all ranges should be checked to insure that shunts are in tolerance.

SECTION X
PARTS LIST FOR MODEL 3300

REF. DESIG.	DESCRIPTION	HICKOK PART NO.
BT1	BATTERY ASSEMBLY: +14.4, 0, -14.4V	2210-45
BT2	BATTERY: 1.25 Volt, 4AH, "D" size	2210-46
C1	CAPACITOR, VARIABLE: 2-18 pf	3115-66
C2	CAPACITOR, FIXED, POLYCARBONATE: .01 uf, 10%, 630 volts	3092-601
C3	CAPACITOR, FIXED, POLYCARBONATE: .1 uf, 10%, 400 volts	3092-413
C4	CAPACITOR, FIXED, DIPPED MICA: 220 pf, 5%, 500 volts	3096-533
C5	CAPACITOR, FIXED, DIPPED MICA: 270 pf, 5%, 500 volts	3096-535
C6	CAPACITOR, FIXED, DIPPED MICA: 390 pf, 5%, 500 volts	3096-539
C7	CAPACITOR, FIXED, POLYESTER FILM: 2.2 uf, 20%, 100 volts	3103-81
C8	CAPACITOR, FIXED, POLYESTER FILM: .047 uf, 20%, 250 volts	3103-79
C9	CAPACITOR, FIXED, CERAMIC: 1000 pf, +50-20%, 500 volts	3111-522
C10, C11	CAPACITOR, FIXED, POLYESTER FILM: .22 uf, 20%, 100 volts	3103-80
C12	CAPACITOR, FIXED, DIPPED MICA: 150 pf, 5%, 500 volts	3096-529
C13	Same as C4	
C14	Same as C5	
C15, C16	CAPACITOR, FIXED, SILVER MICA: cement coated, 330 pf, 2%, 500 volts	3095-306
C17	CAPACITOR, FIXED, CERAMIC: 2200 pf, +50-20%, 500 volts	3111-524
C18	CAPACITOR, FIXED, POLYESTER FILM: .1 uf, 20%, 100 volts	3103-78
C19	CAPACITOR, FIXED, POLYSTYRENE: 270 pf, 5%, 630 volts	3103-91
C20, C21	CAPACITOR, FIXED, POLYSTYRENE: 100 pf, 5%, 630 volts	3103-92
C22 thru C25	Same as C1	
C26	CAPACITOR, FIXED, DIPPED MICA: 22 pf, 10%, 500 volts	3096-509
C27	CAPACITOR, FIXED, POLYCARBONATE: .47 uf, 10%, 400 volts	3092-421
C28	CAPACITOR, FIXED, POLYCARBONATE: .047 uf, 10%, 400 volts	3092-409
C29	CAPACITOR, FIXED, POLYSTYRENE: 4700 pf, 10%, 160 volts	3104-472
C30	CAPACITOR, FIXED, POLYSTYRENE: 470 pf, 10%, 160 volts	3104-471
C31	Same as C9	
C32 thru C34	Same as C18	
C35	Same as C10	
C36	Same as C18	
C37	CAPACITOR, FIXED, DIPPED MICA: 100 pf, 5%, 500 volts	3096-525
C38	CAPACITOR, FIXED, MOLDED COMPOSITION: 3.9 pf, 10%, 500 volts	3116-10
C39, C40	CAPACITOR, FIXED, METALLIZED POLYESTER FILM: 1.0 uf, 10%, 63 volts	3103-58
C41	Same as C17	
C42	Same as C12	
C43	Same as C18	
C44	CAPACITOR, FIXED, ELECTROLYTIC: 100 uf, +50-20%, 70 volts	3085-393
C45, C46, C47	CAPACITOR, FIXED, POLYSTYRENE: calibration, value determined in production	
C48	CAPACITOR, FIXED, POLYSTYRENE: 22 pf, 5%, 630 volts	3103-93
C49	CAPACITOR, FIXED, POLYSTYRENE: 33 pf, 5%, 630 volts	3103-94
C50	CAPACITOR, FIXED, METALLIZED POLYESTER FILM: .01 uf, 10%, 200 volts	3092-201
C51	Same as C18	
CR1 thru CR4	SEMICONDUCTOR DEVICE: diode 1N914	3870-175
CR5, CR6	SEMICONDUCTOR DEVICE: diode, hot carrier	3870-226
CR7	SEMICONDUCTOR DEVICE: zener diode FZ903 ± 10%	3870-243
CR8, CR9	Same as CR1	
CR10	SEMICONDUCTOR DEVICE: zener diode 1N823 A, selected	3870-287 or 3870-288

REF. DESIG.	DESCRIPTION	HICKOK PART NO.
CR11, CR12	SEMICONDUCTOR DEVICE: diode 1N2069	3870-62
CR13	Same as CR7	
CR14 thru CR18	Same as CR1	
DS1	LAMP: pilot, clear red	12270-60
F1	FUSE: 1/4 amp, pigtail, 250 volt	6900-76
P1	PLUG: 6 prong	16525-218
Q1	TRANSISTOR: 2N5139	20861-181
Q2	TRANSISTOR: FET N channel, selected	20861-301
Q3, Q4	TRANSISTOR: FET N channel	20861-252
Q5	TRANSISTOR: 2N5133	20861-210
Q6	TRANSISTOR: FET N channel, selected	20861-253
Q7, Q8	Same as Q5	
Q9	TRANSISTOR: 2N4248	20861-268
Q10	Same as Q5	
Q11	Same as Q6	
Q12	TRANSISTOR: 2N3566	20861-122
Q13	Same as Q3	
Q14	Same as Q9	
Q15	Same as Q5	
Q16	Same as Q9	
Q17	Same as Q5	
Q18, Q19	Same as Q3	
Q20 thru Q25	Same as Q5	
Q26	Same as Q1	
Q27 thru Q31	Same as Q5	
Q32	Same as Q12	
Q33	Same as Q9	
Q34	Same as Q5	
Q35	Same as Q9	
Q36	Same as Q1	
Q37	TRANSISTOR: D16P3	20861-267
Q38	TRANSISTOR: FET N channel, selected	20861-255
Q39	TRANSISTOR: FET N channel, selected	20861-254
Q40	Same as Q38	
Q41, Q42	Not used	
Q43 thru Q45	Same as Q1	
Q46	Same as Q5	
Q47	TRANSISTOR: TD101 NPN differential pair	20861-117
Q48	Same as Q1	
Q49	SEMICONDUCTOR DEVICE: zener diode	3870-242
Q50	Same as Q37	
Q51	Same as Q5	
R1	RESISTOR, FIXED, DEPOSITED CARBON: 10 K ohms, 5%, 1/4 watt	18470-103
R2	RESISTOR, FIXED, DEPOSITED CARBON: 620 K ohms, 5%, 1/4 watt	18470-624
R3	RESISTOR, FIXED, DEPOSITED CARBON: 2 K ohms, 5%, 1/4 watt	18470-202
R4	RESISTOR, FIXED, DEPOSITED CARBON: 270 K ohms, 5%, 1/4 watt	18470-274
R5	RESISTOR, FIXED, DEPOSITED CARBON: 150 K ohms, 5%, 1/4 watt	18470-154
R6	RESISTOR, FIXED, DEPOSITED CARBON: 18 K ohms, 5%, 1/4 watt	18470-183
R7	RESISTOR, FIXED, DEPOSITED CARBON: 39 K ohms, 5%, 1/4 watt	18470-393
R8	Same as R1	
R9	RESISTOR, FIXED, DEPOSITED CARBON: 6.8 K ohms, 5%, 1/4 watt	18470-682
R10	RESISTOR, FIXED, DEPOSITED CARBON: 8.2 K ohms, 5%, 1/4 watt	18470-822
R11	RESISTOR, FIXED, DEPOSITED CARBON: 91 K ohms, 5%, 1/4 watt	18470-913
R12	RESISTOR, FIXED, DEPOSITED CARBON: 47 K ohms, 5%, 1/4 watt	18470-473
R13	RESISTOR, FIXED, DEPOSITED CARBON: 27 K ohms, 5%, 1/4 watt	18470-273
R14	RESISTOR, FIXED, DEPOSITED CARBON: calibration, value determined in production	

REF. DESIG.	DESCRIPTION	HICKOK PART NO.
R15	RESISTOR, FIXED, DEPOSITED CARBON: 51 K ohms, 5%, 1/4 watt	18470-513
R16	Same as R10	
R17	Same as R1	
R18	RESISTOR, FIXED, DEPOSITED CARBON: 3.9 K ohms, 5%, 1/4 watt	18470-392
R19	RESISTOR, FIXED, DEPOSITED CARBON: 62 K ohms, 5%, 1/4 watt	18470-623
R20	RESISTOR, FIXED, DEPOSITED CARBON: 4.7 K ohms, 5%, 1/4 watt	18470-472
R21, R22	Same as R1	
R23	Same as R7	
R24	RESISTOR, FIXED, DEPOSITED CARBON: 3 K ohms, 5%, 1/4 watt	18470-302
R25	RESISTOR, FIXED, DEPOSITED CARBON: 1 megohm, 5%, 1/4 watt	18470-105
R26	Same as R1	
R27	Same as R9	
R28	RESISTOR, FIXED, DEPOSITED CARBON: 24 K ohms, 5%, 1/4 watt	18470-243
R29	RESISTOR, FIXED, METAL FILM: 549 ohms, .5%, 1/4 watt	18554-84
R30, R31	RESISTOR, FIXED, DEPOSITED CARBON: 22 K ohms, 5%, 1/4 watt	18470-223
R32	Same as R1	
R33	RESISTOR, FIXED, DEPOSITED CARBON: 220 K ohms, 5%, 1/4 watt	18470-224
R34	RESISTOR, FIXED, DEPOSITED CARBON: 100 K ohms, 5%, 1/4 watt	18470-104
R35	RESISTOR, FIXED, DEPOSITED CARBON: 470 K ohms, 5%, 1/4 watt	18470-474
R36	Same as R1	
R37	RESISTOR, FIXED, DEPOSITED CARBON: 360 K ohms, 5%, 1/4 watt	18470-364
R38	Same as R1	
R39	Same as R12	
R40	Same as R30	
R41	RESISTOR, FIXED, DEPOSITED CARBON: 33 K ohms, 5%, 1/4 watt	18470-333
R42	Same as R34	
R43	Same as R1	
R44	Same as R41	
R45	Same as R30	
R46	Same as R13	
R47	RESISTOR, FIXED, DEPOSITED CARBON: 560 K ohms, 5%, 1/4 watt	18470-564
R48	RESISTOR, FIXED, DEPOSITED CARBON: 4.3 K ohms, 5%, 1/4 watt	18470-432
R49	RESISTOR, FIXED, COMPOSITION: 8.2 megohms, 10%, 1/4 watt	18455-822
R50	Same as R19	
R51 thru R53	RESISTOR, FIXED, DEPOSITED CARBON: 56 K ohms, 5%, 1/4 watt	18470-563
R54	Same as R25	
R55	RESISTOR, FIXED, DEPOSITED CARBON: 330 K ohms, 5%, 1/4 watt	18470-334
R56	Same as R51	
R57, R58	Same as R14	
R59	RESISTOR, FIXED, COMPOSITION: 3 megohms, 5%, 1/4 watt	18455-301
R60	RESISTOR, FIXED, COMPOSITION: 15 megohms, 5%, 1/2 watt	18416-151
R61	Same as R18	
R62	Same as R3	
R63	Same as R34	
R64	RESISTOR, FIXED, METAL FILM: 1 megohm, 1%, 1/2 watt	18526-75
R65	Same as R33	
R66	RESISTOR, FIXED, METAL FILM: 8.87 megohms, 1%, 2 watt	18575-564
R67	RESISTOR, VARIABLE, COMPOSITION: 300 K ohms, 20%, linear taper	16925-721
R68	RESISTOR, FIXED, METAL FILM: 900 K ohms, .05%, 1/2 watt	18526-70
R69	RESISTOR, FIXED, METAL FILM: 90 K ohms, .05%, 1/2 watt	18526-71
R70	RESISTOR, FIXED, METAL FILM: 9 K ohms, .05%, 1/2 watt	18526-72
R71	RESISTOR, FIXED, METAL FILM: 1 K ohms, .05%, 1/2 watt	18526-73
R72	RESISTOR, FIXED, METAL FILM: 100 ohms, 11%, 1/2 watt	18526-74
R73	RESISTOR, FIXED, WIRE WOUND: 10 ohms, .1%, 1 watt	18550-222
R74	RESISTOR, FIXED, WIRE WOUND: 1 ohms, .1%, 3 watt	18575-566
R75	RESISTOR, FIXED, WIRE WOUND: .1 ohms, .1%, 3 watt	18575-565
R76	RESISTOR, FIXED, METAL FILM: 15 K ohms, 1%, 1/4 watt	18554-73
R77, R78	RESISTOR, FIXED, COMPOSITION: 10 megohms, 5%, 1/4 watt	18456-101
R79	Same as R33	
R80	RESISTOR, VARIABLE, COMPOSITION: 3 K ohms, 20%, linear taper	16925-700

REF. DESIG.	DESCRIPTION	HICKOK PART NO.
R81	RESISTOR, FIXED, DEPOSITED CARBON: 560 ohms, 5%, 1/4 watt	18470-561
R82	RESISTOR, FIXED, COMPOSITION: 100 megohms, 10%, 1/2 watt	18417-102
R83	Same as R77	
R84	RESISTOR, FIXED, DEPOSITED CARBON: 1.5 K ohms, 5%, 1/4 watt	18470-152
R85	Same as R30	
R86	RESISTOR, FIXED, DEPOSITED CARBON: 12 K ohms, 5%, 1/4 watt	18470-123
R87, R88	RESISTOR, FIXED, METAL FILM: 6.81 K ohms, 1%, 1/4 watt	18554-81
R89	RESISTOR, FIXED, METAL FILM: 453 ohms, 1%, 1/4 watt	18554-79
R90	Same as R9	
R91	RESISTOR, FIXED, METAL FILM: 11.3 K ohms, 1%, 1/4 watt	18554-88
R92	Same as R5	
R93	RESISTOR, FIXED, METAL FILM: 2.15 K ohms, 1%, 1/4 watt	18554-111
R94	RESISTOR, VARIABLE, COMPOSITION: 300 ohms, 20%, linear taper	16925-709
R95	Same as R33	
R96	Same as R14	
R97	Same as R80	
R98	Same as R33	
R99	RESISTOR, FIXED, METAL FILM: 5.47 K ohms, .5%, 1/4 watt	18554-110
R100	RESISTOR, FIXED, METAL FILM: 48.7 K ohms, .5%, 1/4 watt	18554-99
R101	RESISTOR, VARIABLE, COMPOSITION: 2.7 K ohms, 20%, linear taper	16925-707
R102	Same as R35	
R103	Same as R82	
R104	Same as R14	
R105	Same as R80	
R106	Same as R14	
R107, R108	RESISTOR, FIXED, METAL FILM: 5.36 K ohms, 1%, 1/4 watt	18554-109
R109	Same as R1	
R110	Same as R30	
R111	Same as R1	
R112	RESISTOR, FIXED, DEPOSITED CARBON: 6.2 K ohms, 5%, 1/4 watt	18470-622
R113	RESISTOR, FIXED, DEPOSITED CARBON: 75 K ohms, 5%, 1/4 watt	18470-753
R114	Same as R1	
R115	Same as R41	
R116	RESISTOR, FIXED, DEPOSITED CARBON: 2.7 K ohms, 5%, 1/4 watt	18470-272
R117	RESISTOR, FIXED, DEPOSITED CARBON: 1 K ohms, 5%, 1/4 watt	18470-102
R118	Same as R34	
R119	Same as R37	
R120	Same as R34	
R121	RESISTOR, FIXED, WIRE WOUND: 370 ohms, 5%, 7 watt	18575-572
R122	RESISTOR, FIXED, WIRE WOUND: 1.9 ohms, 5%, 7 watt	18575-571
R123	RESISTOR, FIXED, DEPOSITED CARBON: 180 K ohms, 5%, 1/4 watt	18470-184
R124	RESISTOR, FIXED, METAL FILM: 61.9 K ohms, 1%, 1/4 watt	18554-83
R125	RESISTOR, FIXED, METAL FILM: 40.2 K ohms, 1%, 1/4 watt	18554-74
R126	RESISTOR, VARIABLE, COMPOSITION: 10 K ohms, 20%, linear taper	16925-704
R127	RESISTOR, FIXED, METAL FILM: 1.5 megohms, 1%, 1/2 watt	18525-928
R128	Same as R24	
R129	RESISTOR, FIXED, COMPOSITION: 20 megohms, 5%, 1/4 watt	18456-201
R130, R131	Same as R33	
R132	Same as R12	
R133	Same as R82	
R134	Same as R80	
R135, R136	Same as R34	
R137, R138	Same as R33	
S1	SWITCH: rotary, function	19912-657
S2	SWITCH: rotary, range	19912-658
T1	TRANSFORMER: power	20800-387

REF. DESIG.	DESCRIPTION	HICKOK PART NO.
V1	TUBE: readout DT1707B	20875-280
V2, V3	TUBE: readout DT1705D	20875-281
V4	TUBE: readout DT1704B	20875-279
X1	SOCKET: 6 pin	19350-458
XV1	SOCKET: tube, 9 pin	19350-498
XV2, XV3	SOCKET: tube, 10 pin	19350-496
XV4	SOCKET: tube, 9 pin	19350-497
Z1	INTEGRATED CIRCUIT: operational amplifier	9800-42
Z2	INTEGRATED CIRCUIT: MOS decoder driver	9800-48
	CORD: AC line, with molded plug, gray	3675-49
	LEAD ASSEMBLY: common	12450-446
	PROBE ASSEMBLY: DC volts	16970-93
	PROBE ASSEMBLY: AC - amps - ohms	16970-94

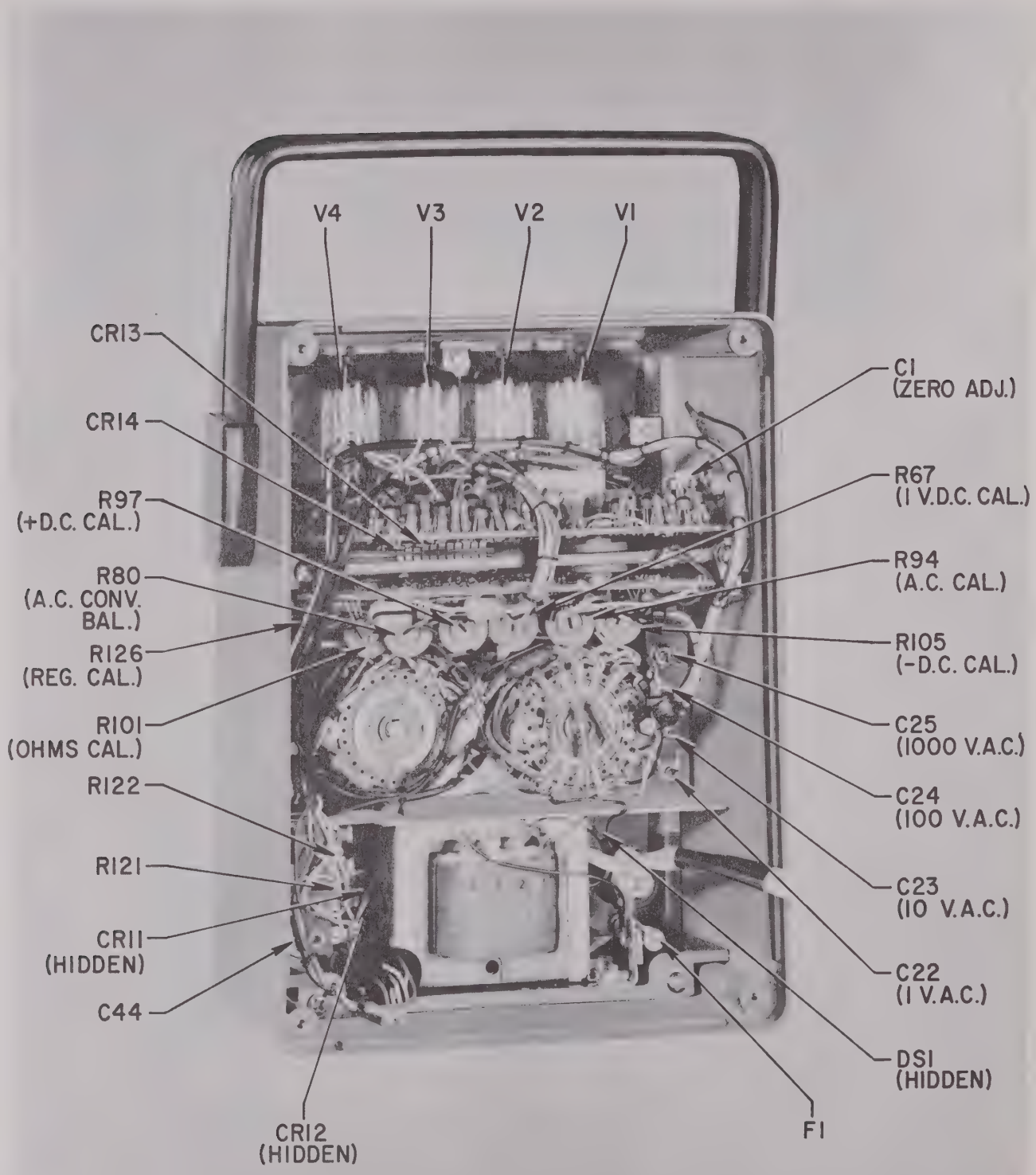


Figure 11. Model 3300, Rear Cover Removed, Parts Location

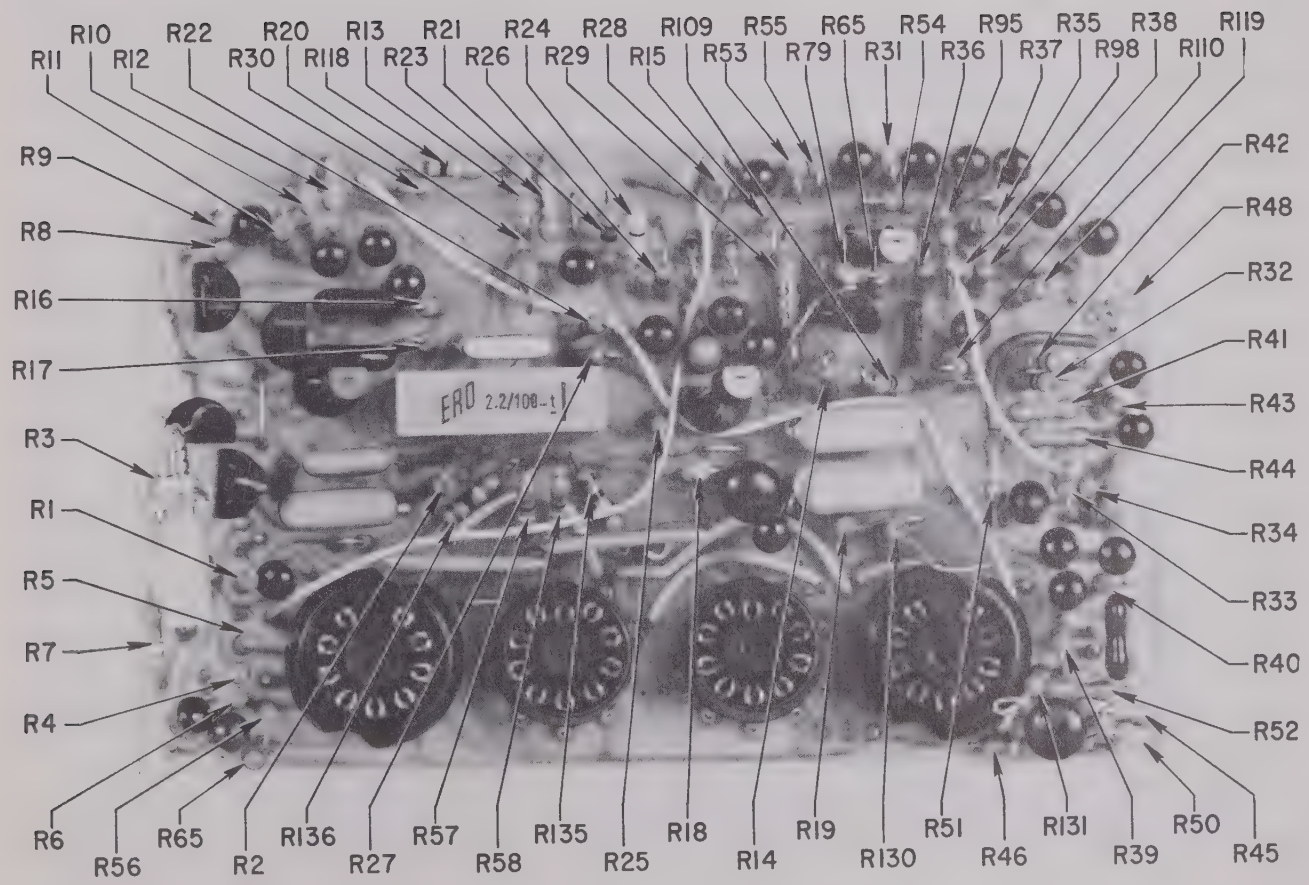


Figure 12. Model 3300, Upper PC Board, Parts Location, Resistors Only

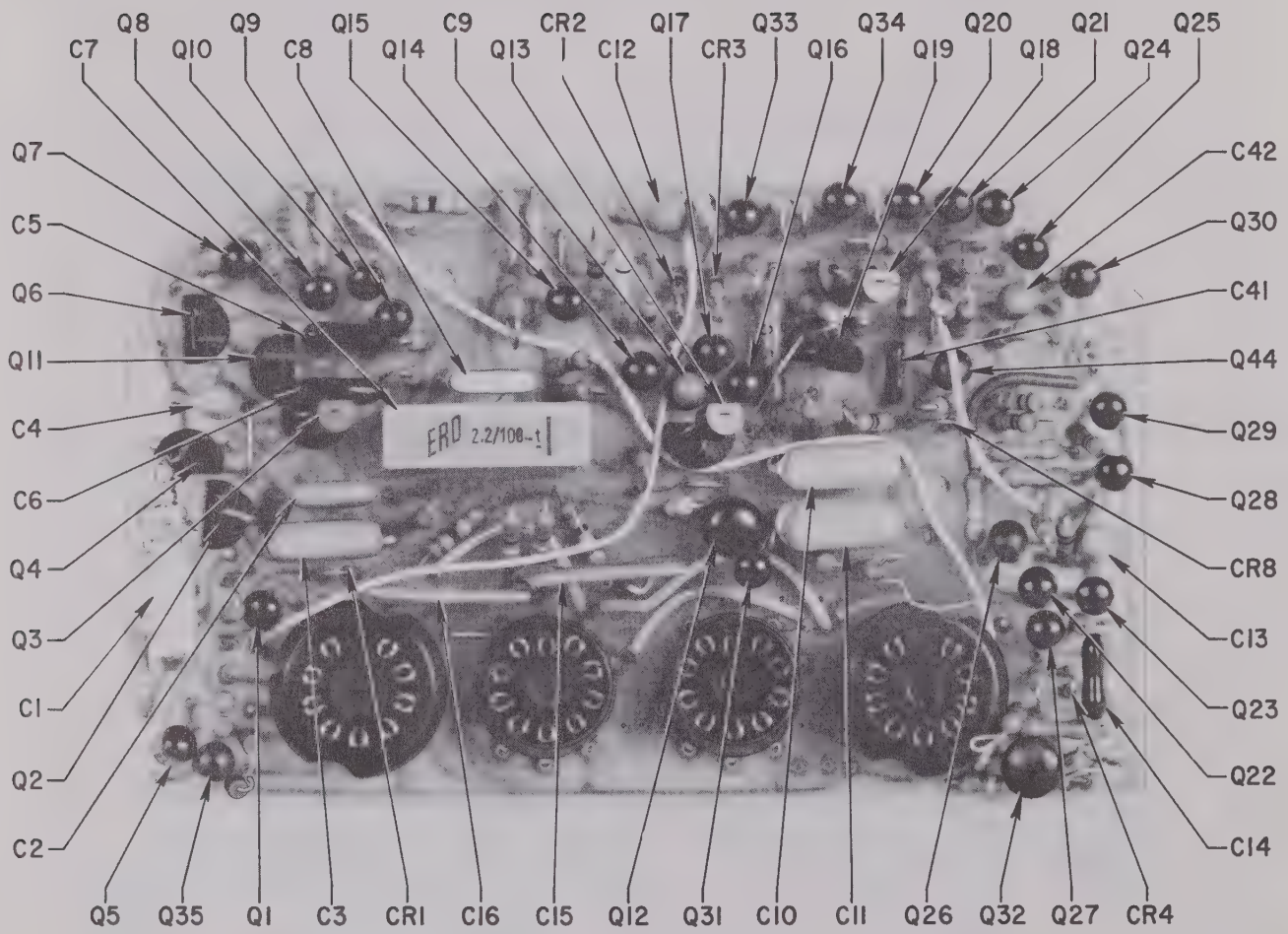


Figure 13. Model 3300, Upper PC Board, Parts Location, Capacitors and Transistors

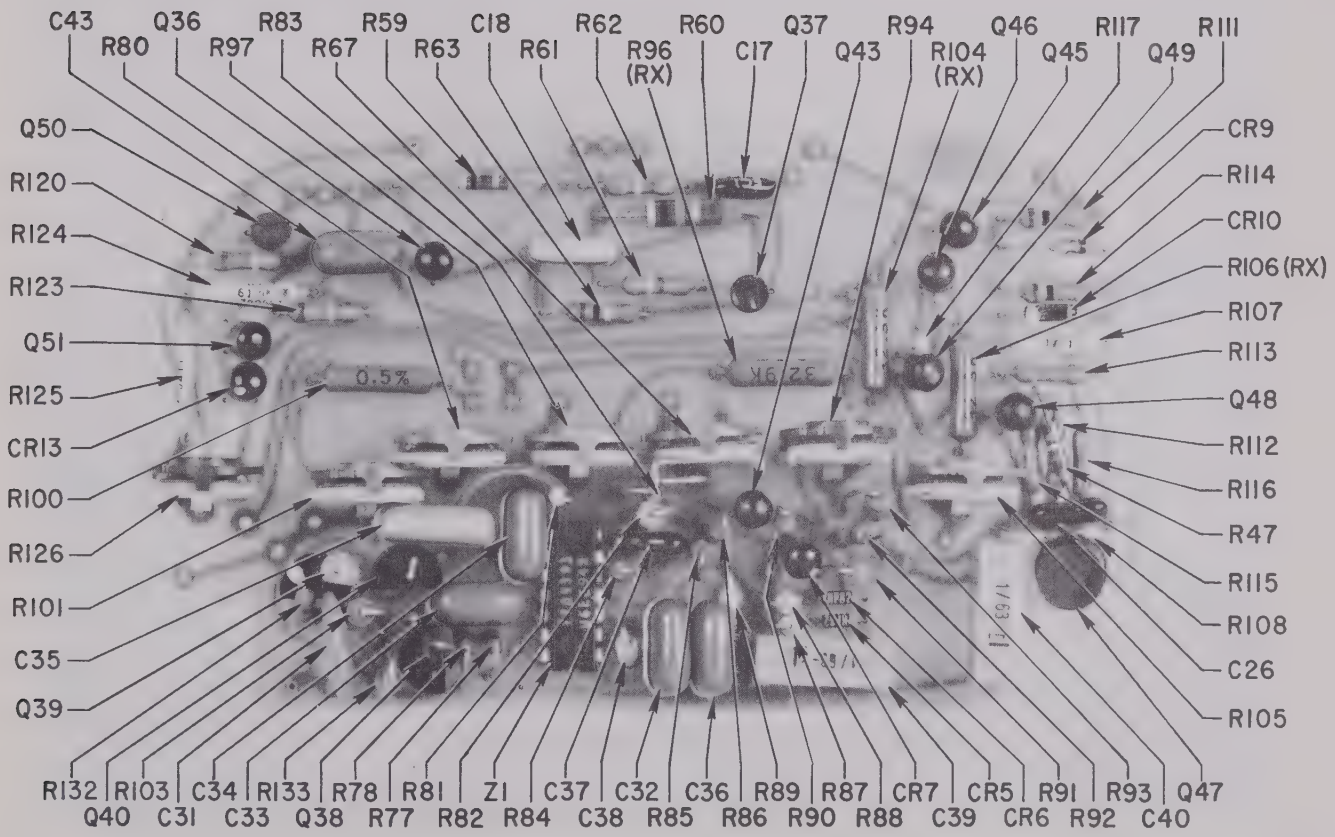


Figure 14. Model 3300, Lower PC Board Parts Locations

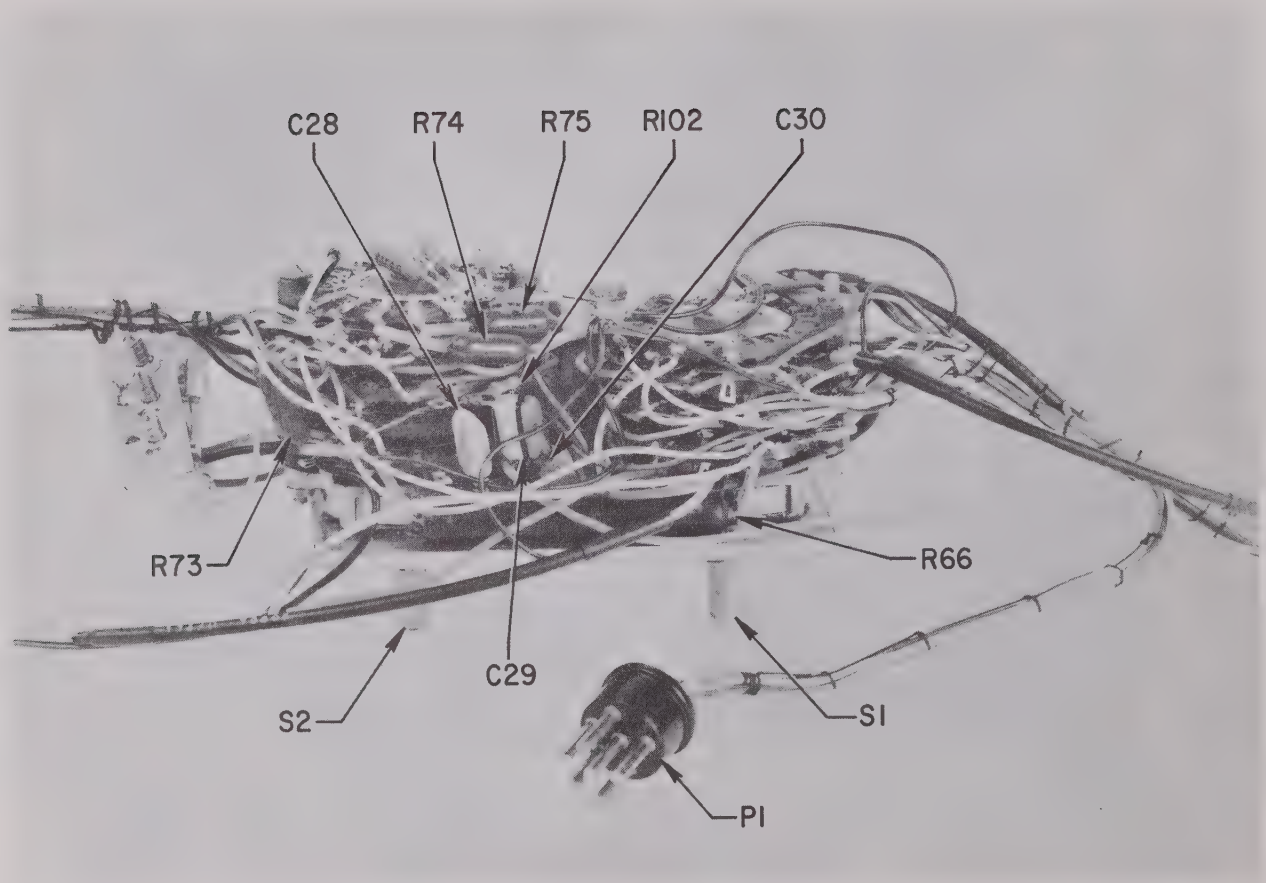


Figure 15. Model 3300, Function and Range Switch Assembly, Top View, Parts Location

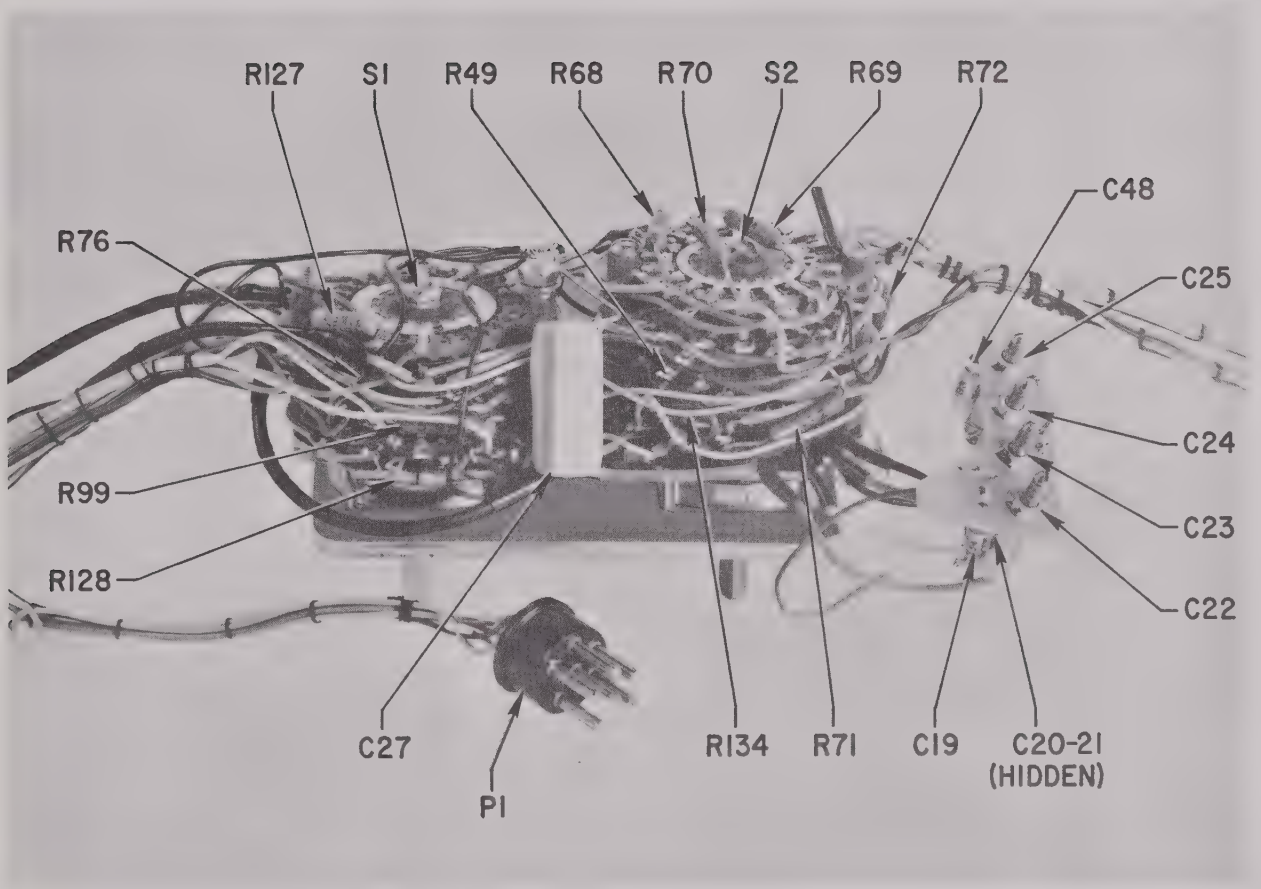


Figure 16. Model 3300, Function and Range Switch Assembly, Bottom View, Parts Location

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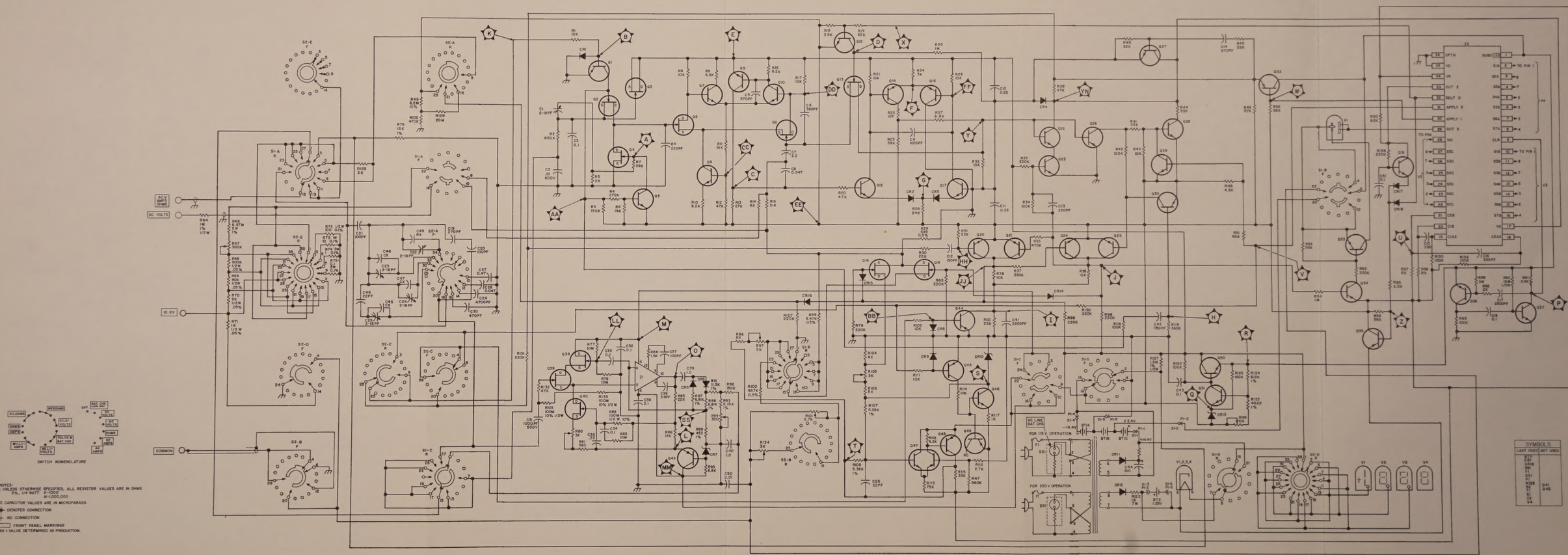

Figure 17. Schematic Wiring Diagram Model 3300 Digital Multimeter